MICROIMAGE / 93-RF-13174

INTEROFFICE MEMORANDUM

6683

DATE: 18 August 1993

FILE: 961.283

TO: J. H. Templeton

RGP DH/for HHB

FROM: R. G. Posgay & H. H. Baker

SUBJECT: Corrosion Evaluation of Polyethylene Containers for Storage of Pond "C" Water and Sludge

REFERENCE: Accelerated Sludge Removal Study - Container Materials of Construction.

This memo is presented in response to your request for additional work, resulting from my previous memo (attached) regarding the unsuitability of carbon steel and stainless steel containers (unlined) for storage of pond materials. Specifically, you informed me that the next best option, polytanks, would need to be considered for the storage of all pond materials. Therefore, an assessment of the corrosion resistance of high density cross linked polyethylene (HDXLPE) to water and sludge in Pond "C", the worst case material, was performed. A thorough review has been made of the chemicals and concentrations which have been listed in the "Characterization Data", received from Halliburton NUS (attached). Based upon this information, conclusions are drawn which are based upon knowledge of the chemical reactions which are considered to be reasonable for the elements presented. The resulting chemical compounds are compared to the chemical resistance data for the HDXLPE material to identify potential problem areas for future analysis.

In order to understand the complexity of the problem and then to understand the rationale upon which this analysis is based, it is necessary to understand the following information:

The chemical "Characterization Data" represents ionic compositions of a wide range of chemical compounds that can exist in the Ponds. As an example, sodium chloride (common table salt) is represented as the separate elements of sodium and chloride. Magnesium chloride is represented as the elements of magnesium and chloride. There are many other chloride compounds which can possibly exist in the actual pond water and/or sludge. It is virtually impossible to identify every type of candidate compound which contains some form of chloride. Many compounds can result from reactions within the ponds, resulting in a host of other compounds such as magnesium and sodium derivatives that could form magnesium sulfate (Epsom salts) or sodium nitrate, etc.

We cannot identify any *inorganic compounds* that might be present in the pond water or sludge which can adversely affect the HDXLPE material. Most chemical attack by inorganic compounds occurs because of high concentrations and elevated temperatures. The concentrations shown in the "Characterization Data" are too low to have an adverse affect and maintaining the temperatures below 100 °F will also help to reduce the chemical attack to insignificant rates.

The content of ***organic compounds***, which are in parts per billion, can be expected to concentrate in the HDXLPE material. The maximum concentration of these compounds which are available within a completely filled 6400 gallon tank (i.e., typical tank available from Poly Processing Co., literature attached) is:

Total weight of 6400 gallons of Pond "C" water = 6400 X 8.33 X 1.332
= **71,011 pounds of Pond "C" water**

2 Butanone (Methyl Ethyl Ketone or MEK @ 76 ppb) = 71,011 X .000000076
= **0.0054 pounds per tank**

Methylene Chloride (Common Paint Stripper @ 5.6 ppb) = 71,011 X .0000000056
= **0.00004 pounds per tank**

Note: The weight of a U.S. 5 cent coin is about 0.011 pounds

It is important to establish that these calculated concentrations are distributed throughout the liquid. It is assumed that all of this material will be absorbed within the HDXLPE within a 1 year period rather than the design life of 10 years. The weight of the HDXLPE actually exposed to the liquid is approximately 1800 pounds per tank (estimate based upon vendor literature). This results in a concentration of 0.00030 by weight (0.00544 / 1800). The manufacturers literature states that the HDXLPE can absorb up to 7% by weight of these type compounds with a resulting reduction of only 10% in the tensile strength of the material. We feel that 0.00030% establishes that there will not be a measurable reduction in the strength of the tank due to absorption of the active organic compounds.

The ***other organic constituent*** of the Pond "C" water is the Total Organic Carbon (TOC) which is reported at 1400 ppm. The maximum concentration of the TOC which is available within a completely filled 6400 gallon tank is:

TOC @ 1400 ppm = 71,011 X 0.0014
= **99.4 pounds of TOC per tank**

This calculated concentration is not evenly distributed throughout the liquid. It is assumed that approximately 10% of the material will form as a floating scum/sludge at or near the waterline. Approximately 40 % of the material is expected to remain in suspension and the remaining 50% should settle to the bottom as sediment. The tank manufacturers product information sheets (attached) indicate that the thickness of the tank wall is tapered from the bottom to approximately the midpoint and then a constant thickness to the top. The actual thickness is dependent upon the design specific gravity (SG) of the contained product. The thickness of the bottom is not published; however, the manufacturer advises that the thickness distribution varies across the tank bottom, with the center section being the thinnest point. The manufacturer's data is not adequate; however, Section 6.4 of ASTM D 1998-91 (Attached) Standard Specification for Polyethylene Upright Storage Tanks addresses the bottom head and states that "The minimum thickness for a full-supported flat-bottom tank shall not be less than 0.187 in. The radius of the bottom knuckle of a flat-bottom tank shall not be less than ...... 1.5 in. (38.1 mm) for a diameter greater than 6 ft. (1.8 m). The minimum thickness of the radius shall not be less than the maximum thickness of the cylinder wall." From this we ascertain that the bottom knuckle is the critical area of the tank bottom and the knuckle radius must be equal to the wall thickness. The Poly Processing Company tanks are manufactured to this ASTM Standard and the manufacturer has made 5 ultrasonic thickness measurements across the tank and reports that average thickness at the bottom of the respective Product Information Sheet.

The tank designed for a SG of 1.9 is used for calculation purposes for the Pond "C" analysis. The inner tank nominal wall thickness is 0.99 inches at the bottom and tapers to 0.5 inch at a height of 7 feet. The nominal wall thickness from 7 feet to 12 feet remains constant at 0.5 inches. The average thickness of the bottom plate is 0.87 inches.

The manufacturers literature (see section 3 of "General Chemical Resistance Chart") states that certain chemicals do not attack the HDXLPE but can be absorbed. The TOC falls into this category. The influence of this absorption within each of the zones is:

Waterline

Pounds of TOC at waterline = 99.4 pounds per tank X 10% TOC @ waterline
= **9.94 pounds of TOC @ Waterline**

Pounds of HDXLPE in a 6 inch band at waterline =
wall thickness (0.5") X width (6") X circumference (361") = 1083 cubic inches
1083 / 1728 = 0.627 cubic feet
0.627 X 58.56 pounds/cubic foot = **36.7 pounds of HDXLPE**

The 9.94 pounds of TOC at the waterline is greater than 7% of the weight of the HDXLPE at the waterline. Therefore, the HDXLPE is expected to absorb the TOC and lose 10% of its tensile strength.

Bottom

Pounds of TOC at bottom = 99.4 pounds per tank X 50% TOC @ bottom
= **49.7 pounds of TOC @ Bottom**

The weight of the HDXLPE in the container bottom cannot be determined from the data available from the manufacturer at this time; however, the ASTM design criteria is reportedly satisfied and the supported flat bottom area is a low stress area and will not be adversely affected by 7% absorption of the TOC.

Sidewall

Not considered due to the large mass of HDXLPE

The waterline is the only place within the container that has the tensile strength degraded by 10% due to the absorption of the TOC. To account for this loss, the allowable hoop stress is reduced from 600 PSI to 540 PSI. This reduction is applicable over the entire height of the wall. The calculated minimum thickness (from Poly Processing Company and ASTM D 1998) is:

T (Wall thickness in inches) = P (Pressure in PSI) X D (Diameter in inches)/(2 X Hoop Stress)

i.e. for a SG = 1.331 T = (0.433 X 1.331 X 12.5 Ft) X 115 In / (2 X 540 PSI)

= 0.768 In.

The minimum wall thickness of the 115 inch diameter Poly Processing Company tank designed for a fluid with a specific gravity of 1.9 exceeds the required 0.768 inch thickness and is satisfactory for a hoop stress calculation of 540 PSI.

The ***radiation level*** of Pond "C" has also been of concern due to the information presented in the attached publication by K. Wundrich (Radiation Resistance for Commercial Plastic and Elastomeric Materials). A specialist from our Industrial Hygiene Department was contacted to evaluate the radiation level of the Pond "C" Water and Sludge. His opinion is that the radiation exposure which the HDXLPE will get from the contents of the storage materials will be less than 400 rads of total dose during the 10 year life. This dose is less than 0.07% of the level reported to have an affect on the crosslinked polyethylene by K. Wundrich. Wundrich did not extensively address the use of antioxidants as did Roger Clough in the attached publication of Encyclopedia of Polymer Science and Engineering (Second Edition, Vol. 13, Pages 667 - 708). Clough reported that when antioxidants are added to polyethylene, the dose required to reduce the tensile elongation to one half the initial value is between 13 and 36 X 10^5 rads. This is 2 to 6 times that required for polyethylene without antioxidant.

The prospective tank supplier, Poly Processing Company was contacted and questioned about the presence of antioxidants. They reported the use of an antioxidant (used as a stabilizer) at a level slightly higher than Clough had tested.

The combination of low total dose and presence of antioxidants will result in a polymer resistant to this type of radiation exposure.

RECOMMENDATIONS:

1. Jack Templeton advised that the project is considering the use of tanks which are service rated for liquids with a specific gravity of 1.65. Our review of the manufacturers Product Information Sheet for the 1.65 and 1.9 SG tanks indicate that two columns of thicknesses are presented. The nominal wall thickness (WT) column and the minimum WT column meet the ASTM design criteria; however, we do not feel that the use of a +/-20% design thickness tolerance (Section 9.1.3 of ASTM D 1998-91) is appropriate for this project. Therefore, the minimum WT column should not be considered. The tanks rated for a SG of 1.9 should be used for Pond "C" water and sludge. Ponds "A" and "B" can utilize the thinner wall, 1.65 SG Tanks due to the lower SG of their liquids and solids.

2. It is suggested that the 1.9 SG tanks be filled to controlled levels. The control may be based upon weight of product stored (Maximum Weight = 73,100 pounds, approx.) or depth of material filled. If the SG of the stored product is known and below 1.343, the tank can be filled to capacity (12.5 feet). If the SG is greater than 1.343, lower levels will be required. For these situations, refer to the following Table:

SG*	Maximum Fill Depth (Ft.)
1.343	12.5
1.40	12.25
1.402	12.22
1.407	12.19
1.418	12.08
1.593	10.76
1.807	9.48
1.82	9.42
1.998	8.58

* SG values reflect numerical values from the Pond "C" Characterization Data and calculations by J. Templeton (attached).

NOTE: the filled weight of the stored materials should not exceed 73,100 pounds.

3. The design thicknesses, type and source of resin, type and quantity of antioxidant material, etc. used in tanks considered for use on this project must be verified prior to inclusion in an approved supplier list. At this time, Poly Processing Company is the only supplier that has been evaluated. They are considered acceptable. A Quality Assurance and tank acceptance inspection program should also be implemented.

4. It is recommended that any openings in the outer wall of the Poly Processing Company tanks be confined to the cover and/or located at elevations above the fill height.

5. It is suggested that a test program be initiated to evaluate the "short term" and "long term" corrosion effects on a range of metallic and non-metallic materials immersed in the various ponds. Data of this type would be of value in evaluating materials and also for site personnel in making future materials and equipment decisions.

6. Some questions have been raised about the use of a 60 mil thickness liner for use inside metal containers. I feel that the problems associated with that approach should be the subject of another memo; however, any sharp edges or burrs in the steel, weld imperfections such as buckshot and splatter, dirt or gravel, liner undersize (causing stress points), liner oversize (causing wrinkles), etc. can result in leaks in the liner. The metal would then corrode, resulting in a perforation of the steel and resultant leakage. The only way that a metal container should be considered is with adequate surface preparation and application of a corrosion resistant lining system.

If you have any questions or require additional information, please call Ray Posgay at 713-676-7061.

Attachments:

1. Interoffice Memorandum, R.G. Posgay to J.H. Templeton, "unlined Carbon Steel Containers - Not Acceptable", 29 July 1993.
2. Pond Sludge Characterization Data, Supplied by Mark Speranza, HNUS.
3. Product Information Sheets from Poly Processing Company.
4. ASTM D 1998-91 Standard Specification for Polyethylene Upright Storage Tanks.
5. Fax from J.H. Templeton to Ray Posgay, "S.G. of Pond Sludge", 9 Aug. 1993.
6. Publication, K. Wundrich, "Radiation Resistance for Commercial Plastic and Elastomeric Materials.
7. Publication, R. Clough, "Radiation Resistant Polymers", Encyclopedia of Polymer Science and Engineering, Second Edition, Vol. 13, Pages 667 - 708, 25 Records.

CC: B&R Project File
T.N. Ivers W/O Attachments
R.P. Negri W/O Attachments
J.R. Zak

INTEROFFICE MEMORANDUM

DATE: 29 July 1993

FILE: 961.283

TO: J. H. Templeton

FROM: R. G. Posgay

SUBJECT: Unlined Carbon Steel Containers - Not Acceptable
Rocky Flats Corrosion Review

REFERENCE: Accelerated Sludge Removal Study - Container Materials of Construction

This memo is a presented in response to your request for a recommendation concerning the use of unlined carbon steel containers to hold pond sludge and water from Ponds A & B.

Any carbon steel container must be lined to store water from any of the Ponds. The presence of a base metal (container) + oxygen (from the air and water) + an electrolyte (Pond water) results in an active corrosion reaction that will cause the container to rust through and leak. An unlined stainless steel container is also unacceptable.

If you have any questions or require additional information, please call me at 713-676-7061.

Ray

Raymond G. Posgay

CC: B&R Project File
J.R. Zak
R.P. Negri

TABLE 3-2

SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207A
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)	ug/l	0/3	ND	ND	ND	ND
SEMIVOLATILES(2)	ug/l	0/3	ND	ND	ND	ND
ALCOHOLS(2)	mg/l	0/3	ND	ND	ND	ND
INORGANICS						
Arsenic	ug/l	3/3	188-224	205	18	8.8
Barium	ug/l	3/3	135-141	139	3.2	2.3
Boron	ug/l	3/3	1400-1460	1430	30	2.1
Cadmium	ug/l	1/3	5	3	1.4	43
Calcium	ug/l	0/3	ND	ND	ND	ND
Chromium	ug/l	3/3	38-49	44	5.6	13
Lead	ug/l	0/3	ND	ND	ND	ND
Magnesium	ug/l	3/3	120,000-124,000	123,000	2300	1.9
Mercury	ug/l	0/3	ND	ND	ND	ND
Nickel	ug/l	0/3	ND	ND	ND	ND
Potassium	ug/l	3/3	388,000-397,000	394,000	4900	1.2
Selenium	ug/l	0/3	ND	ND	ND	ND
Silver	ug/l	0/3	ND	ND	ND	ND
Sodium	ug/l	3/3	1,840,000-1,870,000	1,860,000	17,320	0.9
TCLP LEACH						
Arsenic	ug/l	3/3	233-246	238	6.8	2.8
Barium	ug/l	0/3	ND	ND	ND	ND
Cadmium	ug/l	R	R	R	R	R
Chromium	ug/l	0/3	ND	ND	ND	ND
Lead	ug/l	0/3	ND	ND	ND	ND
Mercury	ug/l	0/3	ND	ND	ND	ND
Nickel	ug/l	0/3	ND	ND	ND	ND
Selenium	ug/l	0/3	ND	ND	ND	ND
Silver	ug/l	1/3	6	4	1.7	43
pH	units	3/3	9.6-9.7	9.6	--	--

TABLE 3-2
SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207A
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
MISCELLANEOUS						
Alkalinity (Methyl Orange)	mg/l	3/3	250	250	0.0	0.0
Alkalinity (Phenolphthalein)	mg/l	3/3	84-89	87	2.5	2.9
Ammonia	mg/l	3/3	0.3	0.3	0.0	0.0
Chloride	mg/l	3/3	380-430	400	25	6.2
Cyanide-Amenable	mg/l	0/3	(-0.79)-(-0.47)	-0.63	--	--
Cyanide-Total	mg/l	3/3	0.39-0.47	0.43	0.04	9.3
Gross Alpha	pCi/l	3/3	610-790	690	91.6	13
Gross Beta	pCi/l	3/3	1000	1000	0.0	0.0
Nitrate	mg/l	3/3	970-1000	980	17.3	1.8
pH	units	3/3	9.7	9.7	0.0	0.0
Phosphorus, Total (as P)	mg/l	3/3	0.06-0.07	0.06	0.006	9.1
Specific Gravity		3/3	1.010-1.012	1.011	0.001	0.1
Sulfate (as SO_4)	mg/l	3/3	460-510	480	26.4	0.6
TDS (Total Dissolved Solids)	mg/l	3/3	7600-7900	7800	153	2.0
TOC (Total Organic Carbon)	mg/l	3/3	68-70	69	1.0	1.4
TSS (Total Suspended Solids)	mg/l	3/3	14-23	19	4.6	24

ND Not Detected
R Rejected

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the <u>Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A)</u>. Interim Final, December 1989.

(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.

9.

10.

TABLE 3-3

SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207A
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS
VOLATILES[1]			
1,1,1-Trichloroethane	ug/kg	1/1	24
1,1,2-Trichloro-1,2,2-trifluoroethane	ug/kg	1/1	260
Tetrachloroethene (PCE)	ug/kg	1/1	290
Trichloroethene (TCE)	ug/kg	1/1	29
SEMIVOLATILES[1]	ug/kg	0/1	
ALCOHOLS[1]	mg/kg	0/1	
MISCELLANEOUS			
Ammonia	mg/kg	1/1	36
Atterberg - Liquid Limit	--	1/1	83
Atterberg - Plastic Index	--	1/1	49
Atterberg - Plastic Limit	--	1/1	34
Bulk Density (Dried Solids)	g/cc	NA	NA
Cyanide-Amenable	mg/kg	NA	NA
Cyanide-Total	mg/kg	1/1	1.6
Gross Alpha	pCi/g	1/1	570
Gross Beta	pCi/g	1/1	95
Moisture-Gravimetric	%	1/1	87.3
Moisture-Karl Fisher	%	1/1	34
pH	units	1/1	8.9
Specific Gravity	--	1/1	1.1
Swell Test	%	1/1	40
TOC (Total Organic Carbon)	mg/kg	1/1	14,000
Chloride[2]	mg/l	1/1	20
Nitrate[2]	mg/l	1/1	35
% Recovery of Solids[2]	%	1/1	11.6
Phosphorus, Total (as P)[2]	mg/l	1/1	0.1
Sulfate[2]	mg/l	1/1	20
TDS (Total Dissolved Solids)[2]	mg/l	1/1	480
INORGANICS			
Arsenic	mg/kg	1/1	40.2
Barium	mg/kg	1/1	210
Boron	mg/kg	1/1	84.3
Cadmium	mg/kg	1/1	1300
Chromium	mg/kg	1/1	658
Lead	mg/kg	1/1	89
Magnesium	mg/kg	1/1	11,400
Mercury	mg/kg	0/1	ND
Nickel	mg/kg	1/1	102
Potassium	mg/kg	0/1	ND
Selenium	mg/kg	0/1	ND
Silver	mg/kg	0/1	ND
Sodium	mg/kg	1/1	14,500
TCLP LEACH			
Arsenic	ug/l	1/1	185
Barium	ug/l	1/1	1710
Cadmium	ug/l	1/1	485
Chromium	ug/l	0/1	ND
Lead	ug/l	0/1	ND
Mercury	ug/l	0/1	ND
Nickel	ug/l	0/1	ND
Selenium	ug/l	0/1	ND
Silver	ug/l	0/1	ND
pH	units	1/1	6.1

NA Not Analyzed
pCi/g Picocuries per Gram
ND Not Detected
(1) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.
(2) Following ASTM Leach

TABLE 3-4

SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207B NORTH
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)	ug/l	0/4	ND	ND	ND	ND
SEMIVOLATILES(2)	ug/l	0/4	ND	ND	ND	ND
ALCOHOLS(2)	mg/l	0/4	ND	ND	ND	ND
INORGANICS						
Arsenic	ug/l	3/4	60-63	51	21	41
Barium	ug/l	4/4	117-120	118	1	1
Boron	ug/l	4/4	149-171	157	10	6
Cadmium	ug/l	0/4	ND	ND	ND	ND
Calcium	ug/l	4/4	137,000-140,000	138,000	1400	1
Chromium	ug/l	2/4	10-16	9	5	58
Lead	ug/l	0/4	ND	ND	ND	ND
Magnesium	ug/l	4/4	64,800-65,900	65,200	480	0.7
Mercury	ug/l	0/4	ND	ND	ND	ND
Nickel	ug/l	0/4	ND	ND	ND	ND
Potassium	ug/l	4/4	55,700-56,400	55,900	340	0.6
Selenium	ug/l	1/4	76	42	23	55
Silver	ug/l	0/4	ND	ND	ND	ND
Sodium	ug/l	4/4	254,000-345,000	296,000	41,000	14
TCLP LEACH						
Arsenic	ug/l	R	R	R	R	R
Barium	ug/l	4/4	215-230	221	7	3
Cadmium	ug/l	0/4	ND	ND	ND	ND
Chromium	ug/l	1/4	16	8	6	71
Lead	ug/l	0/4	ND	ND	ND	ND
Mercury	ug/l	0/4	ND	ND	ND	ND
Nickel	ug/l	0/4	ND	ND	ND	ND
Selenium	ug/l	0/4	ND	ND	ND	ND
Silver	ug/l	0/4	ND	ND	ND	ND
pH	units	4/4	8.3-8.5	8.4	--	--

11.

TABLE 3-4
SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207B NORTH
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
MISCELLANEOUS						
Alkalinity (Methyl Orange)	mg/l	4/4	110	110	0.0	0.0
Alkalinity (Phenolphthalein)	mg/l	3/4	2-3	2	1	55
Ammonia	mg/l	4/4	0.3-0.5	0.4	0.1	28
Chloride	mg/l	4/4	96-100	98	1.7	2
Cyanide-Amenable	mg/l	4/4	(-0.017)-(-0.014)	-0.006	--	--
Cyanide-Total	mg/l	4/4	0.016-0.043	0.030	0.01	36
Gross Alpha	pCi/l	4/4	40-52	47	6.4	14
Gross Beta	pCi/l	4/4	75-510	290	177	61
Nitrate	mg/l	4/4	310-330	320	8	3
pH	units	4/4	8.3-8.5	8.4	--	--
Phosphorus, Total (as P)	mg/l	4/4	0.02-0.08	0.05	0.02	52
Specific Gravity	--	4/4	1.008	1.008	0.0	0.0
Sulfate (as SO_4)	mg/l	4/4	120-160	130	20	15
TDS (Total Dissolved Solids)	mg/l	4/4	2700-2800	2800	50	1.8
TOC (Total Organic Carbon)	mg/l	4/4	35-37	36	1	2.3
TSS (Total Suspended Solids)	mg/l	1/4	15	7.5	5	66

ND Not Detected
R Rejected
pCi/l Picocuries per Liter

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A). Interim Final, December 1989.
(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.

12.

TABLE 3-5

SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207B NORTH
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)	ug/kg	0/4	ND	ND	ND	ND
SEMIVOLATILES(2)	ug/kg	0/4	ND	ND	ND	ND
ALCOHOLS(2)	mg/kg	0/4	ND	ND	ND	ND
MISCELLANEOUS						
Ammonia	mg/kg	4/4	9.8-35	22	10.4	47
Atterberg - Liquid Limit	--	4/4	71-75	73	1.7	2
Atterberg - Plastic Index	--	4/4	34-40	37	3.2	8
Atterberg - Plastic Limit	--	4/4	33-37	36	1.9	5
Bulk Density (Dried Solids)	g/cc	4/4	0.84-0.90	0.87	0.025	3
Cyanide-Amenable	mg/kg	NA	NA	NA	NA	NA
Cyanide-Total	mg/kg	0/4	ND	ND	ND	ND
Gross Alpha	pCi/g	4/4	5.2-11	8.9	2.55	29
Gross Beta	pCi/g	4/4	5.1-9.8	7.3	2.38	33
Moisture-Gravimetric	%	4/4	71.8-76.8	75.1	2.25	3
Moisture-Karl Fisher	%	4/4	23.5-27.9	25.6	1.81	7
pH	units	4/4	7.6-7.7	7.7	--	--
Specific Gravity	--	4/4	1.2	1.2	0.00	0.0
Swell Test	%	4/4	0-10	7.5	5.00	67
TOC (Total Organic Carbon)	mg/kg	4/4	3000-3400	3200	170	5
Chloride(3)	mg/l	4/4	4-24	12	8.6	71
Nitrate(3)	mg/l	4/4	1.7-9.8	6.8	3.6	53
% Recovery of Solids(3)	%	4/4	16.6-25.8	20.8	4.16	20
Phosphorus, Total (as P)(3)	mg/l	4/4	0.01-0.05	0.03	0.02	61
Sulfate(3)	mg/l	4/4	150-160	155	5.8	40
TDS (Total Dissolved Solids)(3)	mg/l	4/4	160-220	190	25.8	14
INORGANICS						
Arsenic	mg/kg	0/4	ND	ND	ND	ND
Barium	mg/kg	4/4	89.1-116	105	11.7	11
Boron	mg/kg	1/4	12.8	7.3	1.2	16
Cadmium	mg/kg	3/4	6.7-8.5	7.1	0.9	13
Chromium	mg/kg	4/4	7.9-33.3	23.2	11.9	51
Lead	mg/kg	4/4	13.8-21.3	15.8	3.6	23
Magnesium	mg/kg	4/4	3270-4160	3805	380	10
Mercury	mg/kg	2/4	0.7-0.8	0.5	0.3	72
Nickel	mg/kg	2/4	7.1-9.5	6.2	2.6	42
Potassium	mg/kg	0/4	ND	ND	ND	ND
Selenium	mg/kg	0/4	ND	ND	ND	ND
Silver	mg/kg	0/4	ND	ND	ND	ND
Sodium	mg/kg	0/4	ND	ND	ND	ND

13.

TABLE 3-5
SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207B NORTH
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
TCLP LEACH						
Arsenic	ug/l	R	R	R	R	R
Barium	ug/l	4/4	1060-1210	1140	76.1	7
Cadmium	ug/l	4/4	54-104	73	21.6	29
Chromium	ug/l	3/4	10-57	22	24.2	111
Lead	ug/l	0/4	ND	ND	ND	ND
Mercury	ug/l	0/4	ND	ND	ND	ND
Nickel	ug/l	3/4	20-56	28	19.8	69
Selenium	ug/l	0/4	ND	ND	ND	ND
Silver	ug/l	0/4	ND	ND	ND	ND
pH	ug/l	4/4	5.7-5.9	5.8	0.1	2

NA Not Analyzed
ND Not Detected
pCi/g Picocuries per Gram
R Rejected

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A). Interim Final, December 1989.
(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.
(3) Following ASTM Leach

14.

TABLE 3-6

SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207B CENTER
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)	ug/l	0/4	ND	ND	ND	ND
SEMIVOLATILES(2)	ug/l	0/4	ND	ND	ND	ND
ALCOHOLS(2)	mg/l	0/4	ND	ND	ND	ND
INORGANICS						
Arsenic	ug/l	4/4	314-330	321	7	2.1
Barium	ug/l	4/4	68-70	69	1	1.4
Boron	ug/l	4/4	3440-3530	3480	40	1.1
Cadmium	ug/l	0/4	ND	ND	ND	ND
Calcium	ug/l	4/4	26,400-27,700	27,000	600	2.3
Chromium	ug/l	4/4	22-32	28	5	16.7
Lead	ug/l	0/4	ND	ND	ND	ND
Magnesium	ug/l	4/4	216,000-220,000	218,000	2000	0.7
Mercury	ug/l	0/4	ND	ND	ND	ND
Nickel	ug/l	4/4	28-31	29	1	4.9
Potassium	ug/l	4/4	791,000-807,000	800,000	8000	1.0
Selenium	ug/l	1/4	81	43	26	59.6
Silver	ug/l	0/4	ND	ND	ND	ND
Sodium	ug/l	4/4	2,060,000-4,060,000	3,150,000	823,000	26.1
TCLP LEACH						
Arsenic	ug/l	4/4	180-251	221	31	14.2
Barium	ug/l	2/4	214-258	162	87	53.8
Cadmium	ug/l	1/4	5	3	1	40.0
Chromium	ug/l	3/4	20-27	20	8	42.2
Lead	ug/l	0/4	ND	ND	ND	ND
Mercury	ug/l	0/4	ND	ND	ND	ND
Nickel	ug/l	3/4	21-30	24	4	17.0
Selenium	ug/l	0/4	ND	ND	ND	ND
Silver	ug/l	0/4	ND	ND	ND	ND
pH	units	4/4	9.1-9.2	9.1	--	--

15.

TABLE 3-6
SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207B CENTER
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
MISCELLANEOUS						
Alkalinity (Methyl Orange)	mg/l	4/4	1400	1400	0.0	0.0
Alkalinity (Phenolphthalein)	mg/l	4/4	230-240	235	6	2.4
Ammonia	mg/l	4/4	0.2-0.4	0.3	0.1	27.2
Chloride	mg/l	0/4	ND	ND	ND	ND
Cyanide-Amenable	mg/l	4/4	(-0.83) - (-5.3)	-1.97	--	--
Cyanide-Total	mg/l	4/4	0.34-0.57	0.40	0.12	28.9
Gross Alpha	pCi/l	4/4	1800-2300	2100	210	10.1
Gross Beta	pCi/l	4/4	2700-3000	2900	130	4.5
Nitrate	mg/l	4/4	1900-2100	2000	100	5.1
pH	units	4/4	9.1-9.2	9.1	--	--
Phosphorus, Total (as P)	mg/l	4/4	4.2	4.2	0.0	0.0
Specific Gravity	--	4/4	1.016-1.018	1.017	0.001	0.10
Sulfate (as SO_4)	mg/l	4/4	740-1000	880	109	12.4
TDS (Total Dissolved Solids)	mg/l	4/4	16,000	16,000	0.0	0.0
TOC (Total Organic Carbon)	mg/l	4/4	93-320	155	110	71.4
TSS (Total Suspended Solids)	mg/l	2/4	11-16	9	5.3	57.5

ND Not Detected
pCi/l Picocuries per Liter

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the <u>Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A)</u>: Interim Final, December 1989.

(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.

16.

TABLE 3-7
SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207B CENTER
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)						
Tetrachloroethene (PCE)	ug/kg	2/4	37-180	70	73	105
SEMIVOLATILES(2)	ug/kg	0/4	ND	ND	ND	ND
ALCOHOLS(2)	mg/kg	0/4	ND	ND	ND	ND
MISCELLANEOUS						
Ammonia	mg/kg	4/4	25-58	43	14	32
Atterberg - Liquid Limit	---	4/4	77-85	83	4	5
Atterberg - Plastic Index	---	4/4	20-40	29	9	33
Atterberg - Plastic Limit	---	4/4	45-65	52	9	18
Bulk Density (Dried Solids)	g/cc	4/4	0.81-0.88	0.84	0.03	4
Cyanide-Amenable	mg/kg	NA	NA	NA	NA	NA
Cyanide-Total	mg/kg	4/4	0.34-1.3	0.64	0.45	71
Gross Alpha	pCi/g	4/4	13-19	17	3	17
Gross Beta	pCi/g	4/4	12-16	15	2	13
Moisture-Gravimetric	%	4/4	89.9-93.4	91.3	1.5	2
Moisture-Karl Fisher	%	4/4	42-53	48	5	10
pH	units	4/4	9.1-9.2	9.2	---	---
Specific Gravity	---	4/4	1.0	1.0	0.0	0.0
Swell Test	%	4/4	60-70	63	5	08
TOC (Total Organic Carbon)	mg/kg	4/4	5500-8800	7400	1500	20
Chloride(3)	mg/l	3/4	210-300	200	80	40
Nitrate(3)	mg/l	4/4	50-74	66	11	16
% Recovery of Solids(3)	%	4/4	9.3-13.7	10.5	2.2	21
Phosphorus, Total (as P)(3)	mg/l	4/4	1.4-3.9	2.1	1.1	56
Sulfate(3)	mg/l	4/4	33-90	49	28	57
TDS (Total Dissolved Solids)(3)	mg/l	4/4	670-770	740	45	6

17.

TABLE 3-7
SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207B CENTER
SOLAR POND/PONDCRETE PROJECT - ROCKY FLATS PLANT
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
INORGANICS						
Arsenic	mg/kg	0/4	ND	ND	ND	ND
Barium	mg/kg	4/4	46.5-120	82.3	30	37
Boron	mg/kg	1/4	151	84	46	55
Cadmium	mg/kg	4/4	46.5-84.4	57.9	17.9	31
Chromium	mg/kg	3/4	48.5-130	63.1	52	82
Lead	mg/kg	0/4	ND	ND	ND	ND
Magnesium	mg/kg	4/4	7,190-19,800	12,400	5,300	43
Mercury	mg/kg	1/4	5.5	1.8	2.5	141
Nickel	mg/kg	0/4	ND	ND	ND	ND
Potassium	mg/kg	3/4	10,900-15,400	10,700	4,350	41
Selenium	mg/kg	0/4	ND	ND	ND	ND
Silver	mg/kg	0/4	ND	ND	ND	ND
Sodium	mg/kg	4/4	35,200-54,200	42,000	8,400	20
TCLP LEACH						
Arsenic	ug/l	4/4	122-181	145	26	18
Barium	ug/l	4/4	2660-3690	3220	430	13
Cadmium	ug/l	4/4	114-153	136	17	12
Chromium	ug/l	4/4	11-54	34	22	65
Lead	ug/l	0/4	ND	ND	ND	ND
Mercury	ug/l	0/4	ND	ND	ND	ND
Nickel	ug/l	1/4	28	14.5	9	62
Selenium	ug/l	0/4	ND	ND	ND	ND
Silver	ug/l	0/4	ND	ND	ND	ND
pH	units	4/4	4.9-6.1	5.8	---	---

ND Not Detected
NA Not Analyzed
pCi/g Picocuries per Gram

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A), 'Interim Final,' December 1989.
(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.
(3) Following ASTM Leach

18.

TABLE 3-8

SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207 B SOUTH
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)	ug/l	0/5	ND	ND	ND	ND
SEMIVOLATILES(2)	ug/l	0/5	ND	ND	ND	ND
ALCOHOLS(2)	mg/l	0/5	ND	ND	ND	ND
INORGANICS						
Arsenic	ug/l	5/5	263-276	270	6	3
Barium	ug/l	5/5	110-118	115	3	3
Boron	ug/l	5/5	2730-2800	2760	30	1
Cadmium	ug/l	0/5	ND	ND	ND	ND
Calcium	ug/l	5/5	52,000-52,700	52,400	270	0.5
Chromium	ug/l	3/5	14-21	13	8	59
Lead	ug/l	0/5	ND	ND	ND	ND
Magnesium	ug/l	5/5	187,000-190,000	188,000	1225	0.6
Mercury	ug/l	0/5	ND	ND	ND	ND
Nickel	ug/l	3/5	20-32	19	9	49
Potassium	ug/l	5/5	684,000-696,000	691,000	5100	0.7
Selenium	ug/l	0/5	ND	ND	ND	ND
Silver	ug/l	0/5	ND	ND	ND	ND
Sodium	ug/l	5/5	2,010,000-2,660,000	2,360,000	283,000	12
TCLP LEACH						
Arsenic	ug/l	5/5	167-390	228	93	41
Barium	ug/l	5/5	269-319	291	19	64
Cadmium	ug/l	0/5	ND	ND	ND	ND
Chromium	ug/l	2/5	10-87	22	36	161
Lead	ug/l	0/5	ND	ND	ND	ND
Mercury	ug/l	0/5	ND	ND	ND	ND
Nickel	ug/l	3/5	21-24	17	7	39
Selenium	ug/l	0/5	ND	ND	ND	ND
Silver	ug/l	0/5	ND	ND	ND	ND
pH	units	5/5	9.0	9.0	0.0	0.0

19.

TABLE 3-8
SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207B SOUTH
SOLAR POND/PONDCRETE PROJECT
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
MISCELLANEOUS						
Alkalinity (Methyl Orange)	mg/l	5/5	900-910	905	5.5	0.6
Alkalinity (Phenolphthalein)	mg/l	5/5	140-160	150	7.1	5
Ammonia	mg/l	5/5	0.5-0.6	0.6	0.05	10
Chloride	mg/l	0/5	ND	ND	ND	ND
Cyanide-Amenable	mg/l	0/5	(-0.86) - (-2.6)	---	---	---
Cyanide-Total	mg/l	5/5	0.28-0.31	0.29	0.01	4
Gross Alpha	pCi/l	5/5	1500-2100	1900	250	13
Gross Beta	pCi/l	5/5	2500-2900	2700	164	6
Nitrate	mg/l	5/5	1600-1800	1700	84	5
pH	units	5/5	9.1	9.1	0.0	0.0
Phosphorus, Total (as P)	mg/l	5/5	2.6-2.8	2.8	0.09	3
Specific Gravity		4/4	1.016-1.020	1.019	0.002	0.2
Sulfate (as SO_4)	mg/l	5/5	540-600	560	26	5
TDS (Total Dissolved Solids)	mg/l	5/5	14,000-15,000	15,000	550	4
TOC (Total Organic Carbon)	mg/l	5/5	58-110	92	22	24
TSS (Total Suspended Solids)	mg/l	5/5	11-39	22	11	49

(1) Average calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation manual (Part A), Interim Final, December 1989.

(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-5. The complete database is included in Appendix A.

20

TABLE 3-9

SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207B SOUTH
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)						
Tetrachloroethene (PCE)	ug/kg	5/5	32-460	238	153	64
Trichloroethene (TCE)	ug/kg	3/5	47-57	41	14	34
SEMIVOLATILES(2)	ug/kg	0/5	ND	ND	ND	ND
ALCOHOLS(2)	mg/kg	0/5	ND	ND	ND	ND
MISCELLANEOUS						
Ammonia	mg/kg	4/5	17-34	20	10	53
Atterberg - Liquid Limit	--	4/4	70-101	85	15	18
Atterberg - Plastic Index	--	4/4	28-41	36	6	18
Atterberg - Plastic Limit	--	4/4	41-60	49	9	18
Bulk Density (Dried Solids)	g/cc	NA	NA	NA	NA	NA
Cyanide-Amenable	mg/kg	NA	NA	NA	NA	NA
Cyanide-Total	mg/kg	5/5	0.46-4.1	1.3	1.5	115
Gross Alpha	pCi/g	5/5	31-61	38	13	33
Gross Beta	pCi/g	5/5	21-47	27	11.1	41
Moisture-Gravimetric	%	5/5	88.3-92.3	90.2	1.9	2
Moisture-Karl Fisher	%	4/4	39-50	45	5	11
pH	units	5/5	9.1	9.1	0.0	0.0
Specific Gravity	--	4/4	1.0-1.1	1.1	0.05	5
Swell Test	%	4/4	30-60	45	13	29
TOC (Total Organic Carbon)	mg/kg	5/5	6,800-11,000	8600	1,600	18
Chloride(3)	mg/l	0/5	ND	ND	ND	ND
Nitrate(3)	mg/l	5/5	77-89	84	5	6
% Recovery of Solids(3)	%	5/5	6.4-12.4	8.9	2.2	24
Phosphorus, Total (as P)(3)	mg/l	5/5	0.09-1.7	0.8	0.7	85
Sulfate(3)	mg/l	5/5	23-40	32	6	20
TDS (Total Dissolved Solids)(3)	mg/l	5/5	740-790	760	20	2

21.

TABLE 3-9
SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207B SOUTH
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
INORGANICS						
Arsenic	mg/kg	1/5	59.7	27.7	18.2	65
Barium	mg/kg	5/5	62.2-134	107	33.2	31
Boron	mg/kg	2/5	336-349	166	161	96
Cadmium	mg/kg	5/5	7.4-30.4	22.7	9.3	41
Chromium	mg/kg	5/5	25.2-51.9	38.1	12.0	31
Lead	mg/kg	1/5	61	24	21	86
Magnesium	mg/kg	5/5	5140-15,200	10,500	4,100	39
Mercury	mg/kg	1/5	5	1.4	2.0	72
Nickel	mg/kg	0/5	ND	ND	ND	ND
Potassium	mg/kg	1/5	8910	5720	2,300	40
Selenium	mg/kg	0/5	ND	ND	ND	ND
Silver	mg/kg	0/5	ND	ND	ND	ND
Sodium	mg/kg	4/5	30,000-44,600	30,000	17,000	56
TCLP LEACH						
Arsenic	ug/l	5/5	194-233	211	21	10
Barium	ug/l	5/5	1660-2770	1960	460	23
Cadmium	ug/l	5/5	19-32	24	6	24
Chromium	ug/l	5/5	23-56	41	12	29
Lead	ug/l	0/5	ND	ND	ND	ND
Mercury	ug/l	0/5	ND	ND	ND	ND
Nickel	ug/l	0/5	ND	ND	ND	ND
Selenium	ug/l	0/5	ND	ND	ND	ND
Silver	ug/l	0/5	ND	ND	ND	ND
pH	units	5/5	5.4-5.9	5.7	---	---

ND Not Detected
NA Not Analyzed
pCi/g Picocuries per Gram

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual (Part A), Interim Final, December 1989.. The complete list of compounds analyzed is shown in Table 2-3.
(2) Only compounds with positive detections are listed. The complete data base is included in Appendix A.
(3) Following ASTM Leach

22.

TABLE 3-10

SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207C
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)						
2-Butanone	ug/l	4/5	77-110	76	43	56
Methylene Chloride	ug/l	1/5	8	5.6	1.3	24
SEMIVOLATILES(2)	ug/l	0/5	ND	ND	ND	ND
ALCOHOLS(2)	mg/l	0/5	ND	ND	ND	ND
INORGANICS						
Arsenic	ug/l	5/5	3350-4110	3690	374	10.1
Barium	ug/l	5/5	110-150	130	14	10.9
Boron	ug/l	5/5	437,000-494,000	463,000	26,000	5.6
Cadmium	ug/l	5/5	430-560	490	50	10.3
Calcium	ug/l	0/5	ND	ND	ND	ND
Chromium	ug/l	5/5	3320-3940	3520	250	7.2
Lead	ug/l	2/5	300	210	80	39.1
Magnesium	ug/l	5/5	1300-3870	2790	930	33.3
Mercury	ug/l	0/5	ND	ND	ND	ND
Nickel	ug/l	5/5	2540-2920	2680	170	6.5
Potassium	%	5/5	5.45-5.92	5.58	0.19	3.5
Selenium	ug/l	2/5	600-3000	1980	1400	70.7
Silver	ug/l	0/5	ND	ND	ND	ND
Sodium	%	5/5	13.6-14.2	13.8	0.25	1.8
TCLP LEACH						
Arsenic	ug/l	5/5	4660-5510	4960	330	6.5
Barium	ug/l	0/5	ND	ND	ND	ND
Cadmium	ug/l	5/5	350-560	430	80	18.6
Chromium	ug/l	5/5	2240-9160	3780	3000	79.8
Lead	ug/l	0/5	ND	ND	ND	ND
Mercury	ug/l	0/5	ND	ND	ND	ND
Nickel	ug/l	5/5	2330-4930	2980	1100	37.0
Selenium	ug/l	0/5	ND	ND	ND	ND
Silver	ug/l	5/5	150-430	250	110	44.3
pH	units	5/5	10.2	10.2	0.0	0.0

TABLE 3-10
SUMMARY OF POND WATER CHARACTERIZATION DATA - POND 207C
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
MISCELLANEOUS						
Alkalinity (Methyl Orange)	mg/l	5/5	58,000-63,000	60,000	1900	3.2
Alkalinity (Phenolphthalein)	mg/l	5/5	25,000-32,000	29,000	2500	8.6
Ammonia	mg/l	5/5	1.8-6.4	3.7	2	53.2
Chloride	mg/l	5/5	21,000-25,000	23,000	1600	6.9
Cyanide-Amenable	mg/l	0/5	(-120)-(-0.77)	-34	---	---
Cyanide-Total	mg/l	5/5	3.3-20	7.7	7	91.3
Gross Alpha	pCi/l	5/5	63-130	99	27	27.3
Gross Beta	pCi/l	5/5	170-230	190	23	11.9
Nitrate	mg/l	5/5	57,000-66,000	62,000	3500	5.6
pH	units	5/5	10.0-10.1	10	---	---
Phosphorus, Total (as P)	mg/l	5/5	520-610	570	32	5.7
Specific Gravity	--	5/5	1.316-1.348	1.332	0.02	0.01
Sulfate (as SO_4)	mg/l	5/5	16,000-18,000	17,000	700	4.1
TDS (Total Dissolved Solids)	mg/l	5/5	300,000-510,000	460,000	88,500	19.4
TOC (Total Organic Carbon)	mg/l	5/5	1200-1600	1400	150	11.1
TSS (Total Suspended Solids)	mg/l	5/5	220-1400	530	490	91.5

ND Not Detected
pCi/l Picocuries per Liter

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A). Interim Final, December 1989.

(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.

TABLE 3-11

SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207C
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)						
1,1,2-Trichloro-1,2,2-trifluoroethane	ug/kg	1/5	33	10.2	12.7	125
2-Butanone	ug/kg	5/5	16-160	110	63.3	57
Benzene	ug/kg	2/5	7-31	10.5	11.5	109
Tetrachloroethene (PCE)	ug/kg	5/5	8-73	22.2	28.4	128
Trichloroethene (TCE)	ug/kg	2/5	5-7	3.9	0.96	25
SEMI-VOLATILES(2)						
Pyrene	ug/kg	2/5	190-320	286	56.5	20
ALCOHOLS(2)	mg/kg	0/5	ND	ND	ND	ND
MISCELLANEOUS						
Ammonia	mg/kg	0/5	ND	ND	ND	ND
Atterberg - Liquid Limit	--	4/4	NP	NP	NP	NP
Atterberg - Plastic Index	--	4/4	NP	NP	NP	NP
Atterberg - Plastic Limit	--	4/4	NP	NP	NP	NP
Bulk Density (Dried Solids)	g/cc	NA	NA	NA	NA	NA
Cyanide-Amenable	mg/kg	NA	NA	NA	NA	NA
Cyanide-Total	mg/kg	5/5	13-170	72	80.5	111
Gross Alpha	pCi/g	5/5	2700-8700	5000	2,400	49
Gross Beta	pCi/g	5/5	420-1200	710	314	44
Moisture-Gravimetric	%	5/5	34.8-48.8	44.0	5.9	13
Moisture-Karl Fisher	%	NA	NA	NA	NA	NA
pH	units	5/5	10.2-10.5	10.4	--	--
Specific Gravity	--	NA	NA	NA	NA	NA
Swell Test	%	4/4	0-10	3	5	200
TOC (Total Organic Carbon)	mg/kg	5/5	6400-9000	7700	1100	14
Chloride(3)	mg/l	5/5	660-990	770	126	16
Nitrate(3)	mg/l	5/5	8900-11,000	10,000	750	7
% Recovery of Solids(3)	%	5/5	9.2-18.8	11.6	4.0	35
Phosphorus, Total (as P)(3)	mg/l	5/5	22-38	31	7.5	24
Sulfate(3)	mg/l	5/5	810-1300	970	190	20
TDS (Total Dissolved Solids)(3)	mg/l	5/5	18,000-24,000	21,000	2,600	12

TABLE 3-11
SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - POND 207C
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
INORGANICS						
Arsenic	mg/kg	5/5	18-37	28	7.9	28
Barium	mg/kg	5/5	13.2-61.5	31	18.3	59
Boron	mg/kg	5/5	455-781	612	128.3	21
Cadmium	mg/kg	5/5	27.3-665	164(4)	280.5	171
Chromium	mg/kg	5/5	252-960	618	256.9	42
Lead	mg/kg	5/5	7.9-38.5	19.4	11.6	60
Magnesium	mg/kg	5/5	1340-6250	3370	1836.0	54
Mercury	mg/kg	5/5	0.7-1.0	0.9	0.1	16
Nickel	mg/kg	5/5	17.4-146	52.3(5)	52.8	101
Potassium	mg/kg	5/5	64,500-87,200	78,100	8640	11
Selenium	mg/kg	0/5	ND	ND	ND	ND
Silver	mg/kg	5/5	35.1-73.6	54.1	14.0	26
Sodium	mg/kg	5/5	139,000-193,000	157,600	21,570	14
TCLP LEACH						
Arsenic	ug/l	5/5	447-538	506	37.3	7
Barium	ug/l	3/5	481-559	377	186.0	49
Cadmium	ug/l	5/5	342-5230	1490(6)	2100	142
Chromium	ug/l	5/5	1840-3940	2770	841	30
Lead	ug/l	2/5	33-52	26	16.5	63
Mercury	ug/l	1/5	0.4	0.2	0.13	84
Nickel	ug/l	5/5	563-2140	986(7)	654	66
Selenium	ug/l	0/5	ND	ND	ND	ND
Silver	ug/l	5/5	9-23	18	5.9	33
pH	units	5/5	4.8-5.3	5.1	--	--

ND Not Detected
NA Not Analyzed
pCi/g Picocuries per Gram
NP Not possible to analyze due to nature of solids

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund Volume 1, Human Health Evaluation Manual (Part A). Interim Final, December 1989.
(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.
(3) Following ASTM Leach
(4) When the Pond Sludge Berm Composite (Sample PS207C-CB) value of 665 is excluded, the average falls to 38.8 mg/kg.
(5) When the Pond Sludge Berm Composite (Sample PS207C-CB) value of 146 is excluded, the average falls to 28.9 mg/kg.
(6) When the Pond Sludge Berm Composite (Sample PS207C-CB) value of 5230 is excluded, the average falls to 552 mg/kg.
(7) When the Pond Sludge Berm Composite (Sample PS207C-CB) value of 2140 is excluded, the average falls to 698 mg/kg.

26.

TABLE 3-12

SUMMARY OF POND WATER CHARACTERIZATION DATA - CLARIFIER
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
VOLATILES(2)	ug/l	0/4	ND	ND	ND	ND
SEMI-VOLATILES(2)	ug/l	0/4	ND	ND	ND	ND
ALCOHOLS(2)	mg/l	0/4	ND	ND	ND	ND
INORGANICS						
Arsenic	ug/l	4/4	272-342	313	32	10
Barium	ug/l	4/4	30-91	49	29	58
Boron	ug/l	4/4	23,300-34,700	28,000	5,400	19
Cadmium	ug/l	4/4	38-570	221	250	113
Calcium	ug/l	0/4	ND	ND	ND	ND
Chromium	ug/l	4/4	138-825	355	319	90
Lead	ug/l	2/4	34-46	28	15	55
Magnesium	ug/l	4/4	2580-6730	3900	1910	50
Mercury	ug/l	4/4	2.2-4.6	3.5	1.0	28
Nickel	ug/l	4/4	258-393	320	58	18
Potassium	mg/l	4/4	4860-7000	5720	1020	18
Selenium	ug/l	0/4	ND	ND	ND	ND
Silver	ug/l	4/4	66-110	85	20	24
Sodium	mg/l	4/4	9940-14,800	11,940	2310	19
TCLP LEACH						
Arsenic	ug/l	4/4	1400-1800	1540	180	12
Barium	ug/l	0/4	ND	ND	ND	ND
Cadmium	ug/l	1/1(3)	50	50	0	0
Chromium	ug/l	2/4	110-140	58	45	51
Lead	ug/l	0/4	ND	ND	ND	ND
Mercury	ug/l	0/4	ND	ND	ND	ND
Nickel	ug/l	3/4	240-350	250	110	44
Selenium	ug/l	0/4	ND	ND	ND	ND
Silver	ug/l	0/4	ND	ND	ND	ND
pH	units	4/4	10.1	10.1	0	0

27.

TABLE 3-12
SUMMARY OF POND WATER CHARACTERIZATION DATA - CLARIFIER
SOLAR POND/PONDCRETE PROJECT
ROCKY FLAT PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
MISCELLANEOUS						
Alkalinity (Methyl Orange)	mg/l	4/4	5500-8200	6800	1130	17
Alkalinity (Phenolphthalein)	mg/l	4/4	2300-3100	2800	340	12
Ammonia	mg/l	4/4	5-14	9	4	40
Chloride	mg/l	4/4	1600-3200	2090	750	36
Cyanide-Amenable	mg/l	0/4	(-14)-(-3.3)	---	---	---
Cyanide-Total	mg/l	4/4	2.4-3	2.7	0.3	9
Gross Alpha	pCi/l	4/4	16-19	17	2	9
Gross Beta	pCi/l	4/4	22-30	25	4	14
Nitrate	mg/l	4/4	5700-10,000	7300	1900	26
pH	units	4/4	9.9-10	10	---	---
Phosphorus, Total (as P)	mg/l	4/4	78-84	81	3	3
Specific Gravity	---	3/3	1.038-1.044	1.041	0.003	0.3
Sulfate (as SO_4)	mg/l	4/4	2600-3200	2800	280	10
TDS (Total Dissolved Solids)	mg/l	4/4	46,000-68,000	59,000	2200	16
TOC (Total Organic Carbon)	mg/l	4/4	140-190	165	21	13
TSS (Total Suspended Solids)	mg/l	4/4	68-180	140	51	36

ND Not Detected
NA Not Analyzed
pCi/l Picocuries per Liter

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Interim Final, December 1989.
(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.
(3) Three out of four values were rejected during data validation.

28.

TABLE 3-13
SUMMARY OF POND SLUDGE CHARACTERIZATION DATA - CLARIFIER
SOLAR POND/PONDCRETE PROJECT
ROCKY FLATS PLANT, COLORADO
PAGE 2 OF 2

ANALYSIS	UNITS	FREQUENCY OF DETECTION	RANGE OF POSITIVE DETECTIONS	MEAN CONCENTRATION(1)	STANDARD DEVIATION(1)	% RELATIVE STANDARD DEVIATION(1)
INORGANICS						
Arsenic	mg/kg	2/4	13.5-21.9	12	7.2	59
Barium	mg/kg	4/4	94.8-217	183	59.2	32
Boron	mg/kg	4/4	420-1380	930	450	48
Cadmium	mg/kg	4/4	2010-4660	3660	1170	32
Chromium	mg/kg	4/4	1180-3190	2480	894	36
Lead	mg/kg	4/4	83-191	161	52	32
Magnesium	mg/kg	4/4	10,400-24,200	20,500	6250	33
Mercury	mg/kg	4/4	5-14	9	5	51
Nickel	mg/kg	4/4	339-902	700	250	36
Potassium	mg/kg	4/4	28,700-67,900	56,500	18,700	33
Selenium	mg/kg	0/4	ND	ND	ND	ND
Silver	mg/kg	4/4	64.6-166	134.9	47.2	35
Sodium	mg/kg	4/4	39,200-96,300	78,900	27,040	34
TCLP LEACH						
Arsenic	ug/l	4/4	224-282	245	26	10
Barium	ug/l	1/4	530	260	180	70
Cadmium	ug/l	4/4	14,800-25,900	20,650	5390	26
Chromium	ug/l	4/4	214-485	362	119	33
Lead	ug/l	1/4	34	20	10	48
Mercury	ug/l	2/4	0.9-4.9	1.5	2.3	153
Nickel	ug/l	4/4	6990-8300	7400	620	8
Selenium	ug/l	0/4	ND	ND	ND	ND
Silver	ug/l	3/4	10-11	8.5	3.7	43
pH	units	4/4	4.6-4.9	4.75	---	---

ND Not Detected
NA Not Analyzed
pCi/g Picocuries per Gram

(1) Values calculated using 1/2 detection limit for nondetects, based on guidance contained in the Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A). Interim Final, December 1989.
(2) Only compounds with positive detections are listed. The complete list of compounds analyzed is shown in Table 2-3. The complete database is included in Appendix A.
(3) Following ASTM Leach
(4) Samples included: CS-001, CS-001D, CS-002, CS-003.
(5) When the apparent low value of 33.1% from CS-001D is omitted, the average % moisture is 69.8%.

29.

Poly Processing COMPANY

DATE: 8-6-93

TO: Ray Posgay

FROM: "Skip" Bell

SUBJECT: 6400 MR Wall Thickness

COVER SHEET PLUS 4 PAGES

PPC FAX NUMBER: (318) 343-8795

IF ANY PAGES ARE UNCLEAR, PLEASE CONTACT OUT OFFICE AT (318) 343-7565

Enclosed are calculations of wall thickness of 6400 MR Inner + Outer Tanks in both 1.65 + 1.9 S.G.

Thanks

- Skip

1-800-523-9871

Poly Processing Company/Division of Abell Corporation
P.O. Box 4150, Monroe, LA 71211 • Phone (318) 343-7565 • FAX (318) 343-8795

Wall thickness calculations for: 6400 Mushroom Inner

Calculations are based on:
1. An allowable hoop stress of 600 psi
2. A maximum temperature of 100 degrees F
3. A fluid with a specific gravity of 1.65
4. A straight sidewall height of 12.5 feet
5. A diameter of 115 inches
6. A lowest nominal wall thickness of .5 inches

T = P * D / (2 * HS)

where:
T = thickness of tank wall in inches
P = head pressure in psi
D = diameter of tank in inches
HS = allowable hoop stress in psi

WALL HEIGHT IN FEET	NOM. WT IN INCHES	MIN. WT IN INCHES
0	.86	.69
1	.79	.63
2	.72	.58
3	.65	.52
4	.58	.47
5	.51	.41
6	.5	.4
7	.5	.4
8	.5	.4
9	.5	.4
10	.5	.4
11	.5	.4
12	.5	.4

PRODUCT INFORMATION SHEET

We do not have a calculation of the bottom of the tank programed in this readout. We took readings of a tank in inventory and provide the average of five readings taken at various points on the bottom of the tank. Average .76

Calculations are based on:

1. An allowable hoop stress of 600 psi
2. A maximum temperature of 100 degrees F
3. A fluid with a specific gravity of 1.65
4. A straight sidewall height of 12.5 feet
5. A diameter of 122 inches
6. A lowest nominal wall thickness of .5 inches

$$T = P * D / (2 * HS)$$

where:
T = thickness of tank wall in inches
P = head pressure in psi
D = diameter of tank in inches
HS = allowable hoop stress in psi

WALL HEIGHT IN FEET	NOM. WT IN INCHES	MIN. WT IN INCHES
0	.91	.73
1	.84	.67
2	.76	.61
3	.69	.55
4	.62	.5
5	.55	.44
6	.5	.4
7	.5	.4
8	.5	.4
9	.5	.4
10	.5	.4
11	.5	.4
12	.5	.4

We do not have a calculation of the bottom of the tank programed in this readout. We took readings of a tank in inventory and provide the average of five readings taken at various points on the bottom of the tank. Average .88

PRODUCT INFORMATION SHEET

Wall thickness calculations for: 6400 Mushroom Inner

Calculations are based on:
1. An allowable hoop stress of 600 psi
2. A maximum temperature of 100 degrees F
3. A fluid with a specific gravity of 1.9
4. A straight sidewall height of 12.5 feet
5. A diameter of 115 inches
6. A lowest nominal wall thickness of .5 inches

$$T = P * D / (2 * HS)$$

where:
T = thickness of tank wall in inches
P = head pressure in psi
D = diameter of tank in inches
HS = allowable hoop stress in psi

WALL HEIGHT IN FEET	NOM. WT IN INCHES	MIN. WT IN INCHES
0	.99	.79
1	.91	.73
2	.83	.66
3	.75	.6
4	.67	.54
5	.59	.47
6	.51	.41
7	.5	.4
8	.5	.4
9	.5	.4
10	.5	.4
11	.5	.4
12	.5	.4

We do not have a calculation of the bottom of the tank programed in this readout. We took readings of a tank in inventory and provide the average of five readings taken at various points on the bottom of the tank. Average .87

Wall thickness calculations for: 6400 Mushroom Outer

Calculations are based on:

1. An allowable hoop stress of 600 psi
2. A maximum temperature of 100 degrees F
3. A fluid with a specific gravity of 1.9
4. A straight sidewall height of 12.5 feet
5. A diameter of 122 inches
6. A lowest nominal wall thickness of .5 inches

T = P * D / (2 * HS)

where: T = thickness of tank wall in inches
P = head pressure in psi
D = diameter of tank in inches
HS = allowable hoop stress in psi

WALL HEIGHT IN FEET	NOM. WT IN INCHES	MIN. WT IN INCHES
0	1.05	.84
1	.96	.77
2	.88	.7
3	.8	.64
4	.71	.57
5	.63	.5
6	.54	.44
7	.5	.4
8	.5	.4
9	.5	.4
10	.5	.4
11	.5	.4
12	.5	.4

We do not have a calculation of the bottom of the tank programed in this readout. We took readings of a tank in inventory and provide the average of five readings taken at various points on the bottom of the tank. Average. .89

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa 19103
Reprinted from the Annual Book of ASTM Standards, Copyright ASTM
If not listed in the current combined index, will appear in the next edition.

35.

Standard Specification for Polyethylene Upright Storage Tanks[1]

This standard is issued under the fixed designation D 1998; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers flat-bottom, upright, cylindrical tanks molded in one-piece seamless construction by rotational molding. The tanks are molded from polyethylene for above-ground, vertical installation and are capable of containing aggressive chemicals at atmospheric pressure. Included are requirements for materials, properties, design, construction, dimensions, tolerances, workmanship and appearance. Tank capacities are from 500 gal (1900 L) up.

1.2 This specification does not cover the design of vessels intended for use at pressures above atmospheric or vacuum conditions, general purpose, or agricultural tanks. It is also not for vessels intended for use with liquids heated above their flash points, or temperatures above 150°F (66°C) for Type I tanks and 140°F (60°C) for Type II tanks for continuous service. *NFPA Standards 30, Flammable and Combustible Liquids Code, and 31, Standard for Installation of Oil Burning Equipment, should be consulted for installations which may be subject to the requirements of these standards.*

1.3 Special design considerations not covered in this document should be given to vessels subject to superimposed mechanical forces, such as seismic forces, windload or agitation; to vessels subject to service temperature in excess of 73.4°F (23°C); and vessels subject to superimposed pressure exceeding 10 in. (25.4 cm) of water or 0.36 psi (2.5×10^{-3} MPa).

1.4 The following precautionary caveat pertains only to the test method portion, Section 11, of this specification: *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 883 Definitions of Terms Relating to Plastics[2]

D 1693 Test Method for Environmental Stress-Cracking of Ethylene Plastics[3]

D 1928 Practice for Preparation of Compression-Molded Polyethylene Test Sheets and Test Specimens[3]

D 2837 Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials[4]

D 3892 Practice for Packaging/Packing of Plastics[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

F 412 Definitions of Terms Relating to Plastic Piping Systems[4]

2.2 *OSHA Standard:*

29 CFR 1910.106 Occupational Safety and Health Administration, Flammable and Combustible Liquids[7]

2.3 *ANSI Standard:*

B-16.5 Pipe Flanges and Flanged Fittings[8]

2.4 *NFPA Standards:*

30 Flammable and Combustible Liquid Code[9]

31 Installation of Oil Burning Equipment[9]

3. Terminology

3.1 Definitions are in accordance with Definitions D 883 and F 412 and the Association of Rotational Molders (ARM) Glossary of Terms,[10] unless otherwise indicated.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *rotational molding*—a three-stage commercial process consisting of loading the mold with powdered resin, fusing the resin by heating while rotating the mold about more than one axis, and cooling and removing the molded article.

3.2.2 *impact failure*—any crack in the test specimen resulting from the impact and visible in normal room lighting to a person with normal eyesight.

3.2.3 *service factor*—a number less than 1.0 (which takes into consideration all the variables and degrees of safety involved in a polyethylene storage tank installation) which is multiplied by the hydrostatic design basis to give the design hoop stress.

4. Classification

4.1 Tanks meeting this specification are classified according to type as follows, and it is the responsibility of the purchaser to specify Type I or Type II.

---

[1] This specification is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.12 on Olefin Plastics.

Current edition approved June 2, 1991. Published June 1991.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol [illegible]

[4] *Annual Book of ASTM Standards*, Vol 08.04.

[5] *Annual Book of ASTM Standards*, Vol [illegible]

[6] *Annual Book of ASTM Standards*, Vol 14.02.

[7] Available from OSHA, 2900 Newton St., NE, Washington, DC, 20018.

[8] Available from ANSI, 1430 Broadway, New York, NY, 10018.

[9] Available from National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

[10] Available from the Association of Rotational Molders, 435 North Michigan Ave., Suite [illegible], Chicago, IL [illegible].

36.

4.1.1 Type I—Tanks molded from cross-linkable polyethylene.

4.1.2 Type II—Tanks molded from noncross-linkable polyethylene.

5. Materials

5.1 The polyethylene shall preferably be virgin material. Any use of regrind, recycled or reprocessed materials, or combinations of such materials, shall not rely upon the performance data of their original constituents, but must meet the requirements of this standard in its own right.

5.1.1 The polyethylene shall have a stress-cracking resistance of 500 h minimum F50 in accordance with Test Method D 1693, Condition A, full-strength stress-cracking agent. The test specimens may be compression molded or rotational molded. If compression molded, Procedure C of Practice D 1928 shall be followed for both types of polyethylene with a minimum platen temperature of 350°F (177°C). If it is a crosslinkable polyethylene the temperature shall be 390°F (197°C) and the platen shall be kept closed under full pressure for 5 min at the specified temperature in order to bring about the crosslinking reaction. If the test specimens are rotational molded, the conditions for rotational molding shall be similar to the conditions used for molding a tank from this polyethylene.

NOTE 1—The stress-cracking test is not used as an indicator of general chemical resistance of a polyethylene. The polyethylene supplier's or molder's chemical-resistance chart should be referred to for information on the resistance of the polyethylene to specific chemicals or products, or testing of specific products or chemicals should be conducted.

5.2 All tanks used for outdoor installation shall contain an ultraviolet stabilizer at a level adequate to give protection for the intended service life of the tanks. This stabilizer shall be compounded in the polyethylene.

5.3 Pigments may be added at the purchaser's request and must be compatible with the polyethylene, but should not exceed 0.5 % dry blended and 2 % compounded in, of the total weight.

NOTE 2—The use of dry-blended pigments may result in an effect on physical properties, that is, impact strength.

5.4 Each resin used in designing tanks covered by this specification shall have hydrostatic-hoop-stress data available.

6. Design Requirements for Both Type I and Type II Tanks

6.1 *Cylinder Shell (unsupported portion of tanks)*—The minimum required wall thickness of the cylindrical shell at any fluid level shall be determined by the following equation, but shall not be less than 0.187 in. (9.5 mm) thick. The tolerance indicated in 9.1.3 applies to these dimensions.

$$T = \frac{P \times O.D.}{2\,SD} = \frac{0.433 \times S.G. \times H \times O.D.}{2\,SD}$$

T = wall thickness, in. (mm)
SD = hydrostatic design stress, psi (MPa)
P = pressure (.433 × $S.G.$ × H), psi (MPa)
H = fluid head, ft (m)
$S.G.$ = specific gravity of fluid (g/cm³)
$O.D.$ = outside diameter, in. (mm)

6.1.1 The resin shall not be used at a hydrostatic-design-stress level that is not supported by hoop-stress data. The hydrostatic-design-stress is determined by multiplying the hydrostatic-design-basis by a service factor. The hydrostatic-design basis shall be calculated by analyzing testing data by the procedures set forth in the Procedure section of Test Method D 2837. The maximum service factor to be used for wall thicknesses below 0.375 in. (9.5 mm) shall be 0.5. For thicknesses above 0.375 in. (9.5 mm) the maximum service factor shall be 0.475. For example, a hydrostatic design basis of 1260 psi (8.7 MPa) multiplied by the service factor of 0.475 results in a design-hoop-stress of 600 psi (4.2 MPa).

6.1.2 All tank hoop stress shall be derated for service above 73.4°F (23°C).

6.2 *Cylinder shell (externally supported tanks)*—The minimum required wall thickness for the cylinder straight shell must be sufficient to support its own weight in an upright position without any external support, but shall not be less than 0.187 in. (4.7 mm) thick. The tolerance indicated in 9.1.3 applies to these dimensions.

6.3 *Top head*—must be integrally molded with the cylinder shell. The minimum thickness of the top head shall be equal to the top of the straight wall.

6.4 *Bottom head*—Must be integrally molded with the cylinder shall. The minimum thickness for a full-supported flat-bottom head shall be 0.187 in. The radius of the bottom knuckle of a *flat-bottom* tank shall not be less than 1 in. (25.4 mm) for tanks with a diameter less than 6 ft. (1.8 m) and 1.5 in. (38.1 mm) for a diameter greater than 6 ft. (1.8 m). The minimum thickness of the radius shall not be less than the maximum thickness of the cylinder wall.

6.5 *Open-top tanks*—The top edge of open tanks shall be reinforced by design to maintain its shape after installation.

7. Fittings

7.1 Fabricated nozzles, gaskets, and other fitting accessories must be chemically compatible with the materials to be handled in the tanks.

7.2 Openings that are cut in tanks to install fittings must not have sharp corners. Holes should have minimum clearance to insure best performance of fittings.

7.3 The size, location, and specification, etc., for manways and fittings shall be agreed upon between the purchaser and the manufacturer.

7.4 The vents must comply with OSHA 1910.106 (F) (iii) (2) (IV) (9) normal venting for atmospheric tanks, or other accepted standard, or shall be at least as large as the filling or withdrawal connection, whichever is larger but in no case less than 1 in. nominal inside diameter.

7.5 Fittings installed in tanks shall be of appropriate strength to meet manufacturer and purchaser specifications.

7.6 Bolts securing mechanical fittings must be manufactured of materials compatible with tank contents.

7.7 Provisions shall be made to attach hold-down devices to the tanks for outdoor service.

7.8 For all flanged connectors, the flange drilling and bolting shall be in accordance with ANSI/ASME B-16.5 for 150 psi pressure class straddling the principal centerline of the vessel.

8. Performance Requirements

8.1 The following performance requirements shall be met by Type I and Type II tanks:

8.1.1 *Low-Temperature Impact*—Low-temperature im-

37.

pact shall be determined using the test method described in 11.3. The requirements for Type I and Type II tanks are as follows:

wall thickness, in. (mm)	ft-lbs (J) to failure, min.
less than and including 0.25 in. (6.6 mm)	90 (122.0)
0.26 in. (6.6 mm) to and including 0.50 in. (12.9 mm)	100 (135.5)
0.51 in. (12.9 mm) to and including 0.75 in. (19.3 mm)	150 (203.2)
0.76 in. (19.3 mm) to and including 1.00 in. (25.4 mm)	200 (271.0)
greater than 1.00 in. (25.4 mm)	200 (271.0)

8.1.2 *Percent gel, for Type I tanks only*—The percent gel level shall be determined using the test method described in 11.4. The percent gel level for Type I tanks on the inside 0.125 in. (3.2 mm) of the wall shall be a minimum of 60 %.

9. Dimensions and Tolerances

9.1 *General*—All dimensions will be taken with the tank in the vertical position, unfilled. Tank dimensions will represent the exterior measurements.

9.1.2 *Outside diameter*—The tolerance for the outside diameter, including out of roundness, shall be ±3 %.

9.1.3 *Shell wall and head thickness*—The tolerance for thickness shall be ±20 % of the design thickness. The total amount of area on the low side of the tolerance shall not exceed 10 % of the total area and the individual area shall not exceed 1 ft² (.09 m²) in size.

9.1.4 *Placement of fittings*—The tolerance for fitting placements shall be ±0.5 in. (12.7 mm) in elevation and 2° radial at ambient temperature.

10. Workmanship

10.1 Type I finished tank walls shall be free, as commercially practicable, of visual defects such as foreign inclusions, air bubbles, pinholes, pimples, crazing, cracking and delaminations that will impair the serviceability of the vessel. Fine bubbles are acceptable with Type II tanks to the degree in which they do not interfere with proper fusion of the resin melt.

10.2 Because of the differences in various resins used in this application and the molding conditions used, the interior surface characteristics may vary. The acceptable finish shall be predetermined by agreement between the molder and the buyer.

11. Test Methods

11.1 *Test specimens*—Test specimens shall be taken from the manway cut-out area or where fittings are inserted.

11.2 *Conditioning*—If requested, test specimens may be conditioned at 73.4 ± 3.6°F, (23 ± 2°C) and 50 ± 5 % relative humidity for not less than 40 h prior to testing in accordance with Procedure A of Test Methods D 618.

11.3 *Low-Temperature Impact Test*

11.3.1 *Scope*—This method is for the determination of the impact property of rotational-molded polyethylene tanks at low temperature. The method is used on tanks molded from both crosslinked and non-crosslinked polyethylenes.

11.3.2 *Summary of test method*—Test specimens are cut from available areas on the tank and conditioned at −20°F (−29°C) for a specified period of time. A suitable type of test apparatus is shown in Figs. 1 and 2. The specimens are placed, inside-surface down, in the sample holder and

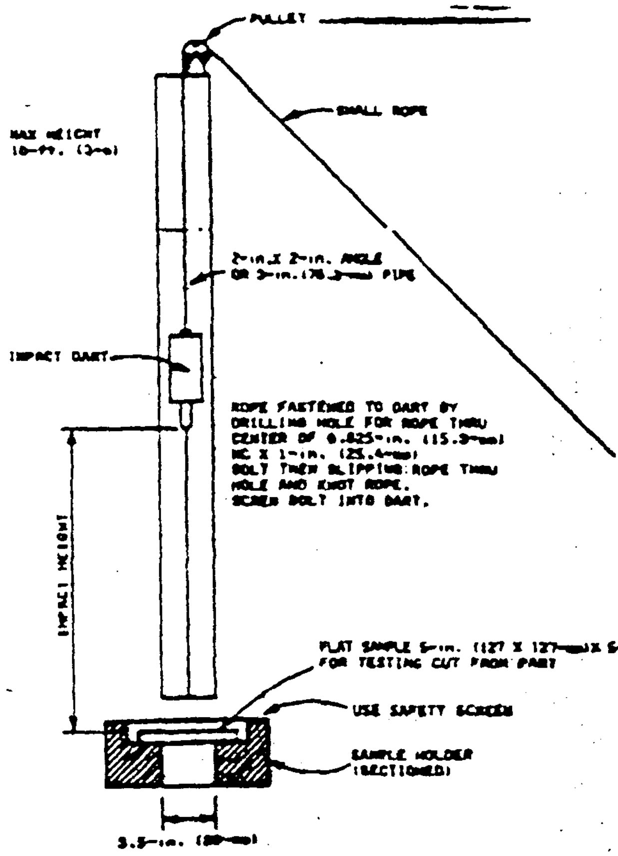

FIG. 1 Dart Drop Impact Test Apparatus

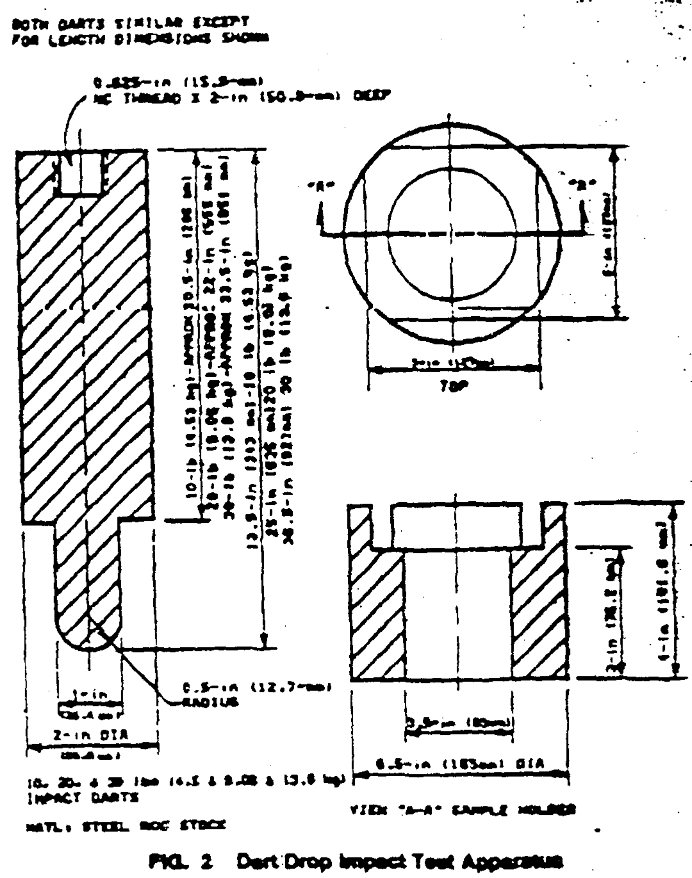

FIG. 2 Dart Drop Impact Test Apparatus

immediately impacted with a dart of specified weight, from a prescribed height with a specified radius on the tip. The specimen is observed for failure on both surfaces. The test prescribes a minimum impact value which the specimen must pass.

11.3.3 *Significance and Use:*

11.3.3.1 The dart impact test at −20°F (−29°C) produces a value that is used as an indication of the quality of the tank. If the molding conditions were inadequate and a homogenous melt was not obtained, the impact will likely be low. Higher impact values are obtained with ideal molding conditions indicating that a quality part with good impact resistance has been molded.

11.3.3.2 The impact test gives a true indication of how well the tank was molded.

11.3.4 *Procedure:*

11.3.4.1 Cut specimens to loosely fit the 5 in. by 5 in. (127 mm by 127 mm) sample holder (see Fig. 2). Specimens shall be approximately 5 in. by 5 in. (127 mm by 127 mm), or the maximum size available. In those tanks where specimens of the above size are not available, the supplier must show correlation data between the smaller size and the recommended size.

11.3.4.2 Cool bath to −20°F (−29°C) by immersing small quantities of dry ice in isopropyl alcohol used as the bath medium.

11.3.4.3 SAFETY WARNING—Care should be exercised as the dry ice will agitate the solution violently.

11.3.4.4 A freezer may be used if available. Immerse the specimens in the bath for a minimum of 30 min while maintaining the bath temperature. More immersion time is required for specimens greater than 0.25 in. (6.4 mm) thick or for specimens chilled in air instead of alcohol. Two hours is recommended for air chilled specimens.

11.3.4.5 Remove specimens singly and impact immediately on the outer surface. Use the impact force specified. The force is calculated by multiplying the dart weight by the impact height (see Fig. 1). The specimen shall not fail at the specified impact value (see 3.2.2 for the definition of failure).

NOTE 4—Ductile failures indicate proper molding for Type I and Type II tanks, while cracking or shattering indicates improperly molded specimens. The test apparatus is shown in Figs. 1 and 2.

11.3.5 *Report the following information:*

11.3.5.1 Identification of the tank,

11.3.5.2 Date of test,

11.3.5.3 Foot-pounds (J) used for the test, and

11.3.5.4 Pass or fail.

11.3.6 *Precision and Bias:*

11.3.6.1 Table 1 is based on a round robin[11] conducted in 1988 in accordance with Practice E 691, involving two materials tested by seven laboratories. For each material, all the samples were prepared at one source, but the individual specimens were prepared at the laboratories which tested them. Each test result was the average of 20 individual determinations. Each laboratory obtained two test results for each material.

NOTE 5: Caution—The following explanations of r and R are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Table 1 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E 691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles shown below would then be valid for such data.

TABLE 1 Precision Summary—−40°F (−40°C) Impact Strength

Material	Average	S_r[A]	S_R[B]	V_r[C]	VR[C]	r[D]	R[D]
2	155.5714	5.1686	16.3623	3.3	10.5	14.4720	45.8146
1	167.5429	6.2398	13.6268	3.7	8.1	17.4700	38.1581
Average:				3.5	9.3		

38.

[A] S_r is the within laboratory repeatability, and

[B] S_R is the between laboratory reproducibility.

[C] V_r and VR are the co-efficients of variation (standard deviation expressed as a percent of the average)

[D] r and R are the 95 % limits for a single sample for repeatability and reproducibility respectively.

11.3.6.2 *Concept of r and R*—If S_r and S_R have been calculated from a large-enough body of data, and for test results that were averages from testing 20 specimens:

(*a*) *Repeatability, r*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, the two test results should be judged not equivalent if they differ by more than the r value for that material.

(*b*) *Reproducibility, R*—In comparing two test results for the same material, obtained by different operators using different equipment on different days, the two test results should be judged not equivalent if they differ by more than the R value for the material.

(*c*) Any judgement in accordance with (*a*) or (*b*) would have an approximate 95 % (0.95) probability of being correct.

11.3.6.3 There are no recognized standards by which to estimate bias of this test method.

11.3.6.4 A round robin is currently in progress using a testing temperature of −20°F (−29°C) to provide data for a precision statement at the same temperature as specified in the test method.

11.4 *O-Xylene-Insoluble Fraction (Gel Test)*

11.4.1 *Scope*—This test method is for determination of the ortho xylene insoluble fraction (gel) of crosslinked polyethylene.

11.4.2 *Summary of Test Method*—A weighed specimen of the crosslinked polyethylene sample is placed in a screen container and the total weight is taken. The container is submerged in boiling o-xylene overnight which dissolves the uncrosslinked portion of the sample. The container with the specimen is dried in an oven and weighed. The percentage gel content is calculated from the weight loss and the original specimen weight.

11.4.3 *Significance of Test*—The o-xylene insoluble portion (gel) of crosslinked polyethylene is an indication of the amount of crosslinking in the polyethylene. The gel is not a direct measure of the extent of the crosslinking network, but indirectly serves to provide a good measure of the crosslinking. It is, therefore, valuable as a test for the quality of the crosslinked polyethylene part.

[11] Supporting data are available from ASTM Headquarters. Request RR: D 20-

11.4.4 *Apparatus:*[12]

11.4.4.1 *Extraction Apparatus:*

(a) Resin Kettle 2-L[13]

(b) Heating Mantle 2-L[14]

(c) Clamp, Resin Kettle[15]

(d) Condenser, with ground taperjoint to fit hole in resin kettle lid

(e) Variable Transformer

(f) Unistrut or equivalent stand with clamp to support the kettle and condenser

(g) Metal pan, for setting the apparatus in to retain the o-xylene in the event the kettle breaks

11.4.4.2 Analytical balance, which weighs to four decimal places

11.4.4.3 Stainless steel screen, 100-mesh

11.4.4.4 Muffle furnace

11.4.4.5 Forced-draft oven

11.4.4.6 Reagents

(a) O-xylene, technical grade

(b) Plastanox 2246, antioxidant[16] or equivalent

11.4.5 *Hazards:*

11.4.5.1 Care should be exercised in handling o-xylene. It may cause irritation to the eyes and prolonged exposure may cause blistering and redness to the skin. Inhalation may cause mucous membrane irritation and other effects. The Material Safety Data Sheet should be consulted prior to its use. O-xylene is listed in Subpart Z—Toxic and Hazardous Substances of 29 CFR Ch. VII (7-1-88 Edition). Other applicable EPA and government standards should be consulted also.

11.4.6 *Test Specimens:*

11.4.6.1 The test specimen shall be from the 0.125 in. (3.2 mm) thickness of the interior wall of Type I tanks. It should be cleanly cut so there are no frayed edges or corners.

11.4.6.2 The specimen shall be taken from a manway, drain opening or similar area which is normally removed from the tank before use.

11.4.7 *Procedure:*

11.4.7.1 Weigh a 0.3 g specimen cut from the molded part to ±0.0002 g. Record the specimen weight as W_1.

11.4.7.2 Cut a 1.5 by 3 in. (35 by 76 mm) piece of 100-mesh stainless steel screen for each specimen. Clean the screen with o-xylene, rinse with acetone, and dry in a stream of air.

11.4.7.3 Fold the screen to form a 1.5 by 1.5 in. (38 by 38 mm) square. Make a fold about ¼ in. (6.4 mm) along each of the two open edges to form a pouch, and staple the folds.

11.4.7.4 Place the specimen into the screen pouch, fold the remaining edge, staple the fold and mark each screen with a metal tag. Do not squeeze the pouch sides together. Leave space for the specimen to swell. Weigh the sample plus screen to +0.0002 g and record this weight as W_2.

NOTE 6—An alternate specimen holder is a reusable cage made from 100-mesh stainless steel screen as shown in Fig. 3. A size of 0.6 in. by 1.4 in. (15.2 mm by 35.6 mm) has been found satisfactory for the cage. The cages must be cleaned after each test by burning off remaining polyethylene at 800°F (427°C) for approximately 30 min in a muffle furnace.

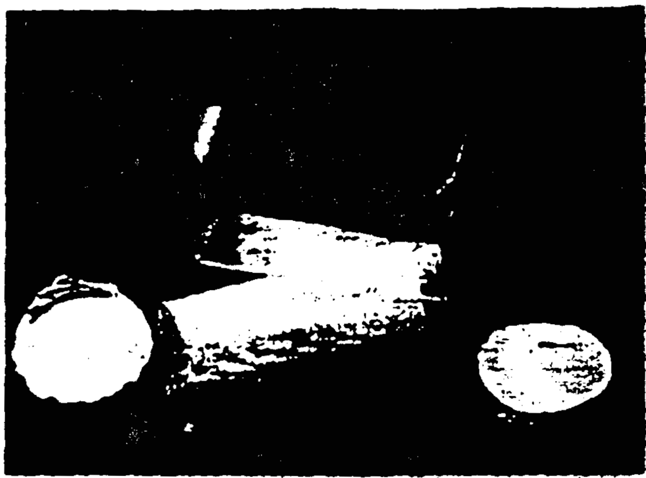

FIG. 3a Gel Cage

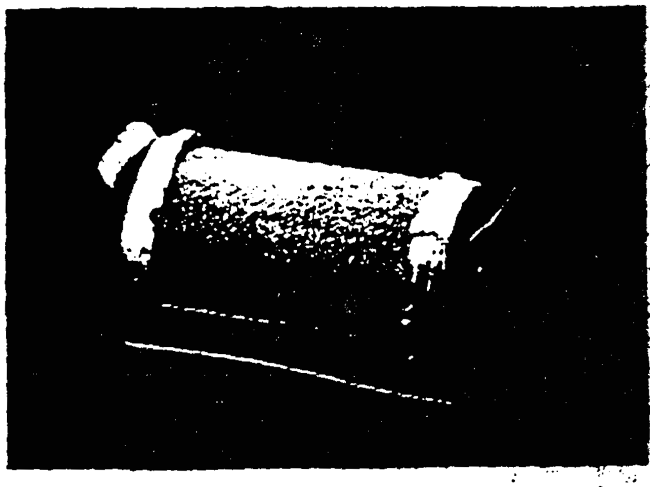

FIG. 3b Gel Cage

11.4.7.5 Place 1500 mL of o-xylene and 10 g of Plastanox 2246 or equivalent antioxidant in the resin kettle and heat to reflux.

NOTE 7—The Plastanox 2246 is added to prevent further crosslinking of the polymer during the extraction.

11.4.7.6 Suspend the sample screen in the refluxing solvent for 16 h. An overnight run is convenient.

NOTE 8—A maximum of eight samples can be tested in one run.

11.4.7.7 Remove the sample screen while hot and dry to constant weight (W_3) in a forced-draft oven at 338°F (170°C)—for about two h.

11.4.8 *Calculation:*

$$\text{Gel Weight \%} = \frac{W_1 - (W_2 - W_3 \times 100)}{W^1}$$

where:

W_1 = weight of sample, g.

W_2 = weight of sample plus screen, g.

[12] Suitable apparatus is available from most laboratory supply firms.

[13] Sargent No. S-34530 or equivalent.

[14] Sargent No. S-40890 or equivalent.

[15] Sargent No. S-34533 or equivalent.

[16] Available from American Cyanamid Co., Organic Chemicals Division, Boundbrooks, NJ, 08805.

TABLE 2 Precision Summary—O-Xylene Insoluble Fraction (Gel)

Material[A]	Average	S_r[B]	S_R[C]	V_r[D]	V_R[D]	r[E]	R[E]
6	78.9806	2.4733	4.1864	3.1	5.2	6.9251	11.7219
5	81.9057	2.1598	3.4861	2.8	4.3	6.0478	9.7612
4	82.1862	1.2954	3.0863	1.6	3.8	3.6271	8.6416
1	84.1072	1.8584	2.9802	2.0	3.5	4.8482	8.3447
7	84.6600	2.0078	2.9978	2.4	3.5	5.6219	8.3938
8	86.4129	1.7201	3.2507	2.0	3.8	4.8164	9.1019
3	91.4138	2.9248	5.1665	3.2	5.7	8.1894	14.4523
2	92.5576	0.9363	1.8244	1.0	2.0	2.6217	5.1083
Average:				2.2	4.0		

[A] The thicknesses of the molded samples from which the specimens were taken were as follows:

	in.	mm
6	>3/4	>19
5	>1/2	>13
4	>1/4	>6
1	1/4	6
7	>3/4	>19
8	1/4	6
3	1/2	13
2	1/4	6

The materials were the same for samples (2 and 3), (4, 5 and 6) and (7 and 8). Sample 1 was different from the others.

[B] S_r is the within-laboratory repeatability and

[C] S_R is the between-laboratory reproducibility

[D] V_r and V_R are the coefficients of variation (standard deviation expressed as a percent of the average)

W_3 = weight of sample plus screen after extraction, g.

11.4.9 *Report the following information:*

11.4.9.1 Identification of the tank,

11.4.9.2 Date of the test,

11.4.9.3 Percentage of gel determined in 11.4.8, and

11.4.10 *Precision and Bias:*

11.4.10.1 Table II is based on a round robin[17] conducted in 1989 in accordance with Practice E 691, involving eight materials tested by seven laboratories. For each material, all the samples were prepared at one source, but the individual specimens were prepared at the laboratories which tested them. Each test result was the average of two individual determinations. Each laboratory obtained three test results for each material.

NOTE 9: Caution—The following explanations of r and R are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Table 2 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E 691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles shown below would then be valid for such data.

11.4.10.2 *Concept of r and R*—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing two specimens:

(*a*) *Repeatability, r*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, the two test results should be judged not equivalent if they differ by more than the r value for that material.

(*b*) *Reproducibility, R*—In comparing two test results for the same material, obtained by different operators using different equipment on different days, the two test results should be judged not equivalent if they differ by more than the R value for the material.

(*c*) Any judgment in accordance with (*a*) or (*b*) would have an approximate 95 % (0.95) probability of being correct.

11.4.10.3 There are no recognized standards by which to estimate bias of this test method.

11.5 *Visual Inspection*—The tank shall be visually inspected to determine such qualities as are discussed in the Workmanship Section.

11.6 *Water Test*—Each tank shall be hydrostatically tested by the supplier. The tank shall be pre-tested at the time of installation by the user by filling completely with water. Such a test also allows final inspection of the proper installation of all fittings.

12. Marking

12.1 The tank shall be marked to identify the producer, date (month and year) of manufacturer, capacity, maximum specific gravity of tank design, serial number and Type I or Type II. The marking shall be permanent.

12.2 The proper caution or warning signs as prescribed by OSHA standard 29 CFR 1910.106 shall be affixed to the tank.

12.3 Tank capacities should be based on total tank volume.

13. Packing, Packaging and Marking

13.1 All packing, packaging, and marking provisions of Practice D 3892 shall apply to this standard.

14. Shipping

14.1 Since there are variations in methods of shipping and handling, the manufacturer's instructions shall be followed in all cases.

14.2 A suitable means shall be provided, if required, at the open end of open-top tanks to keep the loaded tank rigid.

14.3 All fittings and flange faces shall be protected from damage by covering with suitable plywood, hard-board or plastic securely fastened. Tanks shall be positively vented at all times.

14.4 Pipe and tubing, fittings and miscellaneous small parts shall be packaged. Loose items which may scratch the interior surface shall not be placed inside the tank during shipment. Additional protection, such as batens, end wrapping, cross bracing, or other interior fastenings may be required to assure such individual equipment pieces are not damaged in transit.

14.5 Upon arrival at the destination, the purchaser shall be responsible for inspection for damage in transit. If damage has occurred, a claim should be filed with the carrier by the purchaser. The supplier should be notified if the damage is not first repaired by the fabricator prior to the tank being put into service. The purchaser accepts all future responsibility for the effects of the tank failure resulting from damage.

15. Keywords

polyethylene; tanks; upright

[17] Supporting data are available from ASTM Headquarters. Request RR: D 20-

41

CLIENT EG&G Rocky Flats	JOB NUMBER JR-1198
SUBJECT Accelerated Sludge Removal - Corrosion Analysis - Sludge S.G.	
BASED ON Previous Calcs. - Attached	DRAWING NUMBER

BY Templeton	CHECKED BY	APPROVED BY	DATE 8-9-93

B Consolidated Ponds

Sludge could vary from 1.090 → 1.118

It is planned to do as much settling and consolidation of B pond material as possible. Use the maximum ⇒ S.G. = 1.20

C Pond The attached table shows:
Sludge w/ Sat'd Soln S.G. = 1.593 → 1.998
S.G. Sat'd soln = 1.402 → 1.418

Overall, the wt. of sludge is small compared to the entire volume, and C pond will not be settled and decanted, but pumped and left as is.

The overall, s.g. of the pond contents is

$$\left(\frac{4,788,081 \text{ lb.}}{411,717 \text{ gal}}\right) / (8.35 \text{ lb/gal}) = 1.40$$

If, during transport a tank received all C pond sludge it would have an approximate s.g. of:

$$\left(\frac{.60}{2.41} + \frac{.40}{1.34}\right)^{-1} = 1.82$$ (assumes 60% solids in sludge)

As this is near the tank limit of 1.91 s.g. we will do two things
1) Only partly fill tanks if all sludge.

2) Calculate max useable s.g. (based on 1.91 max) and derate for service and lifespan. (Then control fill height to max allowable derated s.g.)

Brown & Root, Inc.

452 Burbank Street
Broomfield, CO 80020 43.

Halliburton NUS/EG&G Rocky Flats Solar Pond Project Site Office

FAX Cover Sheet

DATE 8/9/93 TIME 1205 NO. OF PAGES (incl. cover sheet) 4

PLEASE DELIVER THE FOLLOWING PAGES TO:

NAME RAY POSGAY FAX NUMBER

FROM Jack Templeton P.E. (303) 466-3573

SUBJECT SG of pondsludge

If transmission is incomplete or illegible, please call the phone number listed above

COMMENTS

TRANSMITTED FROM FAX (303) 469-6354

A Halliburton Company

A/B PONDS - CONTENTS AND VOLUME REQUIRED FOR STORAGE

JULY 8, 1993

44.

TOTAL SLUDGE VOLUME				
CURRENT, GALLONS	228,770	228,770	228,770	
CURRENT, CU YD	1,132.60	1,132.60	1,132.60	
TOTAL POND CONTENTS	2,101,431	2,077,077	2,131,299	
DRY SOLIDS, LB.	319,564	280,555	367,672	
TDS IN SLUDGE, LB.	23,307	18,478	29,005	
WATER IN SLUDGE, LB.	1,758,559	1,778,045	1,734,621	
TDS WT%	1.11%	0.89%	1.36%	
TDS VOL%	0.41%	0.28%	0.64%	
TSS WT%	15.21%	13.51%	17.25%	
TSS VOL%	7.31%	6.42%	8.33%	
SLUDGE S.G.	1.103	1.090	1.118	
DRY SOLIDS S.G.	2.293	2.294	2.315	
SOLUTION S.G.	1.010	1.008	1.010	
WATER REQUIRED ABOVE SOLUTION 25,000 GAL PER INCH	75,000	75,000	75,000	
PUMPING S.G.	1.077	1.068	1.089	
WASH WATER, GAL	44,000	44,000	44,000	MEMO TO DIST. From J. Templeton RGF Processing Methodology
POND VOLUME AFTER WATER COVER AND WASHDOWN, GAL	347,770	347,770	347,770	

OPTION A - SLUDGE + WATER COVER + WASH WATER

TOTAL, GAL	347,770
SLUDGE, GAL	228,770
WATER COVER, GAL	75,000
WASH WATER, GAL	44,000

OPTION B - LIKE A BUT DECANT EXCESS WATER

TOTAL, GAL	228,770
SLUDGE, GAL	228,770

OPTION C - DEWATER SLUDGE TO 20.00% BY WT SOLIDS

TOTAL, LB.	1,597,821	1,402,774	1,838,362
TOTAL, GAL	168,902	148,494	193,968
SOLUTION REM., LB.	503,610	674,303	292,937
SOLUTION REM., GAL	59,868	80,277	34,802

OPTION D - DEWATER SLUDGE TO 45.00% BY WT SOLIDS

TOTAL, LB.	710,143	623,455	817,050
TOTAL, GAL	63,377	55,715	72,633
SOLUTION REM., LB.	1,391,288	1,453,622	1,314,249
SOLUTION REM., GAL	165,394	173,055	156,137

C POND CONTENTS AND VOLUME REQUIRED FOR STORAGE

JULY 7, 1993

TOTAL POND VOLUME

GALLONS ON 9/10/92	392,531	392,531	392,531	
CU FT, ON 9/10/92	1,943.35	1,943.35	1,943.35	
SALT SOLUBILITY				
MAX WT%	45.80%	51.05%	42.77%	
WATER REQUIRED TO DISSOLVE SALT				
WATER, GAL	299,155	231,759	361,430	
ADDITIONAL, GAL	19,185	(59,945)	94,162	
TOTAL SOLN REQ., GAL	411,717	332,586	486,693	
WASH WATER, GAL	44,000	44,000	44,000	MEMO TO DIST. From J. Templeton REF Processing Methodology
TOTAL VOLUME INCL. DILUTION & WASHDOWN, GAL	455,717	376,586	530,693	
TDS WT%	45.80%	51.05%	42.77%	PRIOR TO WASH DOWN
TDS VOL%	23.85%	27.24%	22.11%	PRIOR TO WASH DOWN
TSS WT%	6.59%	4.98%	7.48%	PRIOR TO WASH DOWN
TSS VOL%	4.80%	3.58%	5.77%	PRIOR TO WASH DOWN

SLUDGE

VOLUME, GALLONS	38,788	38,788	38,788	VOLUME CALC
VOLUME, CU FT	192.03	192.03	192.03	VOLUME CALC
WT% SOLIDS	59.98%	43.90%	70.50%	MEMO to TAS from R. Ninesteel 6/13/92, REF C-[illegible]
S.G., DRY SOLIDS	2.230	1.93	2.41	MEMO to TAS from R. Ninesteel 6/13/92, REF C-[illegible]
S.G., CONT. SOL'N	1.407	1.402	1.418	MEMO to TAS from R. Ninesteel 6/13/92, REF C-[illegible]
%TDS, CONT. SOL'N	44.78%	45.65%	44.43%	MEMO to TAS from R. Ninesteel 6/13/92, REF C-[illegible]
S.G. SLUDGE	1.807	1.593	1.998	CALCULATED

CRYSTAL

VOLUME, GALLONS	78,450	78,450	78,450	VOLUME CALC
VOLUME, CU FT	388.39	388.39	388.39	VOLUME CALC
WT% SOLIDS	56.00%	51.20%	65.20%	Table 3-11, PS Characterization Report, [illegible]
S.G., DRY SOLIDS	2.200	2.200	2.200	MEMO to TAS from S. Mathew 6/20/92 REF. [illegible]
S.G., CONT. SOL'N	1.407	1.402	1.418	Assume to be the same as the sludge.
%TDS, CONT. SOL'N	44.78%	45.65%	44.43%	Assume to be the same as the sludge.
S.G. CRYSTAL	1.763	1.722	1.846	CALCULATED

SOLUTION

VOLUME, GALLONS	275,294	275,294	275,294	VOLUME CALC
VOLUME, CU FT	1,362.93	1,362.93	1,362.93	VOLUME CALC
S.G. OF SOL'N	1.331	1.321	1.343	TDS DATA FROM [illegible]
%TDS OF SOL'N	36.99%	34.82%	38.72%	TDS DATA FROM 9/10/92

TOTAL POND CONTENTS	4,788,081	4,669,279	4,931,416	
DRY SOLIDS, LB.	350,189	226,004	455,052	
DRY CRYSTAL, LB.	2,105,750	2,013,378	2,250,014	
WATER, LB.	2,332,143	2,429,898	2,226,350	

46.

Radiation Resistance for Commercial Plastic and Elastomeric Materials

K. Wündrich
Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, F.R. Germany

A. INTRODUCTION

1. General Comments

These tables are intended to give a comprehensive survey of radiation resistance by means of listing the change in mechanical properties on the basis of literature data. The values were determined for specific materials tested under special conditions which cannot all be given here or are not completely known. The change in properties depends to a large extent on a number of influence factors which are discussed in the following paragraphs. The reader is advised to use these data with caution considering all these factors.

2. Criterion for Radiation Resistance

The radiation resistance is characterized by the *half-value-dose* of significant mechanical properties. This is defined as the absorbed dose that reduces a property to 50% of the initial value under defined environments. The SI unit gray (Gy), which is related to the old unit rad (rad) by $1\ Gy = 1\ J \times kg^{-1} = 100$ rad, is used. In cases where the experiments were terminated before reaching the 50% decrease of the investigated property, the absorbed dose is given with the sign >.

The properties can be affected differently, and therefore more than one relevant property should be considered. In most cases, suitable properties to characterize the radiation resistance are the elongation at break for flexible plastics and elastomers and the flexural strength for rigid plastics.

For *electrical properties*, such as resistivity, insulation resistance, electric strength, dissipation factor, or permittivity, only a few publications could be found and were not considered here. The mechanical deterioration frequently gives rise to significant electrical changes. For most electrical applications, it may well be that the change in mechanical properties will be the most significant criterion for the radiation resistance. Changes in the dissipation factor or in permittivity may sometimes occur before mechanical degradation is severe. For higher dose rates, the temporary decrease of insulation resistance during irradiation and shortly after, due to radiation-induced conductivity relative to the dose rate, is important.

3. Factors of Influence and Their Consideration in the Tables

The radiation resistance depends on such parameters as the chemical structure of the polymer, the formulation, and the environmental conditions (such as medium, temperature, mechanical and electrical stress, dose rate, etc.). Some of them are considered in the tables.

3.1 *Type of Polymer and Formulation.* The polymeric materials are classified as *thermoplastics*, *elastomers*, and *thermosets*. In the first column of the tables the basic polymer is given. The radiation-induced changes mainly depend on the chemical structure of the polymer chain. The data were obtained by testing commercial materials which contain certain amounts of ingredients. For thermosets, different *fillers*, which generally have a great influence on the radiation resistance, are considered. As a general rule, inorganic fillers increase the resistance and organic fillers decrease it. Further, a good adhesion between resin and reinforcing fillers is significant. The influence of fillers and other *additives* must also be considered for thermoplastics and elastomers. Antioxidants in usual compounding concentrations were found to increase the radiation resistance considerably in air at low dose rates. In general, aromatic compounds have a more favorable influence than aliphatic ones. For the polymer itself it is well known that aromatic groups in the molecule increase the radiation resistance.

3.2 *Type of Radiation and Dosimetry.* The overall radiation effect does not depend on the type of radiation, such as β or γ rays, nuclear radiation, fast electrons, or other particle radiation, but only on the absorbed dose. There are some uncertainties about the given dose. The exposure or flux can be measured with an accuracy of $\pm$ 10%. From this, the absorbed dose is calculated on the basis of the material composition or the density. An error of up to 20% can be made here. Details about the determination of the absorbed dose are in most cases not given.

3.3 *Dose Rate and Atmosphere.* If air is present, the resistance can be a function of the dose rate, depending on the chemical structure of the polymer. The oxygen takes part in the radiation-induced reactions. The effect increases with a decreasing dose rate because it is determined by time-dependent processes: the diffusion of oxygen into the polymer and the decay of generated peroxides. Therefore, at low dose rates the radiation resistance can be up to two orders of magnitude lower than at high dose rates.

The effect of oxygen restricts the prediction of lifetime at low dose rates on the basis of accelerated high-dose rate tests. The effect is most significant for linear polyolefins and some other thermoplastics. For thermosets, only a few results are reported. Here the high density of cross-links and the low diffusion rate of oxygen may decrease the influence of the dose rate.

If no oxygen is present, the radiation resistance seems to be independent of the dose rate. However, if the material is exposed to air after irradiation, post-irradiation oxidation can take place by the reaction of oxygen with residual free radicals. It should be noted that irradiation experiments with low dose rate in vacuum have not been reported.

The influence of air and dose rate is considered by adding a column labelled 'air excluded', meaning irradiation in vacuum or inert gas, before the column labelled 'in air'. The latter is divided into 8 columns with a decreasing dose rate from $\geq 10^5$ to 5 Gy/h. The higher dose rates are based on fast electrons or nuclear radiation, and dose rates of 10^4 Gy/h or lower on γ-rays. Because the radiation resistance in air decreases more or less with decreasing dose rate, a given value from the literature was entered in the column for a dose rate equal or just greater than the real one in the experiment. However, the reader should refer to the column for a dose rate which is equal to or just lower than the service dose rate. The tendency of dose rate dependence is not always clear if the values are taken from different references. Reference numbers for the data are given in parentheses.

The superscript f means films or fibres with a *thickness* of $\leq$0.4 mm. If possible, the real thickness is noted under "Remarks". The amount of oxygen available for reactions increases with decreasing sample thickness. Therefore, thin samples are less resistant than thicker ones.

3.4 *Temperature.* The irradiation temperature is in all cases ambient temperature, i.e., about 25–35°C. As only a few experiments with higher irradiation temperature are reported, they have not been considered here. As a rule, the resistance decreases with increasing temperature. At transition temperatures (melting point, glass transition, and lower secondary transitions) a significant discrete change in activation energy may take place.

3.5 *Other Stresses.* The tables do not consider *mechanical stress and deformation* during irradiation which can influence the radiation resistance to a great extent. For instance, if elastomers are used as sealants, the radiation-induced crosslinking builds up a secondary network which fixes the deformation state. This decreases the recovery stress necessary for the sealing function. In order to obtain this effect, the compression set must be measured after irradiation in the compressed state. Furthermore, *electrical stresses* are to be considered.

B. LIST OF SYMBOLS USED

σ_R	Tensile strength at break (ultimate strength)
σ_B	Tensile strength at maximum load
σ_S	Tensile strength at yield
ϵ_R	Elongation at break (ultimate elongation)
ϵ_{BMax}	Elongation at maximum load
σ_{bB}	Flexural strength
a_n	Impact strength
a_K	Impact strength, notched
f	Fibres or films with a thickness of $\leq$0.4 mm

C. REFERENCES

1. G. C. Collins, V. P. Calkins, APEX-261, 1956.
2. R. Harrington, Nucleonics, **14**, 70 (1956).
3. R. Harrington, Rubber Age, **81**, 971 (1957).
4. H. Wilski, Kunststoffe, **53**, 862 (1963).
5. H. Wilski, Atomwirtschaft, **10**, 70 (1965).
6. H. Fischer, K. -H. Hellwege, W. Langbein, Kunststoffe, **58**, 625 (1968).
7. K. Wündrich, Materialprüfung, **10**, 217 (1968).
8. J. Voigt, private communication, 1969.
9. H. -P. Gilfrich, H. Wilski, Chem. Ing. Tech., **42**, 1231 (1970).
10. V. Kabaivanov, S. I. Hadschidutschewa, Plast und Kautschuk, **17**, 478 (1970).
11. H. Wilski, Europäisches Treffen der Chemischen Technik (Achema), Frankfurt, Germany, June 18, 1970.
12. L. Wuckel, W. Koch, Isotopenpraxis, **8**, 1 (1972).
13. H. Wilski, Kolloid-Z. Z. Polym. **251**, 703 (1973).
14. K. Wündrich, Symposium on Radiation Chemistry of Polymers, Garching near München, Germany, October 24, 1974, AED-CONF-74-456-017.
15. H. Wilski, Progr. Colloid Polym. Sci., **58**, 77 (1975).
16. K. T. Gillen, E. A. Salazar, SAND 78-0344, 1978.
17. N. A. Ghanem et al., Elastomerics **111**, 5, 40 (1979).
18. N. Hayakawa et al., 7th Water Reactor Safety Research Information Meeting, U. S. Nuclear Regulatory Commission, Washington D. C., November 9, 1979.

19. H. Schönbacher, A. Stolarz-Izycka, CERN 79-04, 1979.
20. H. Schönbacher, A. Stolarz-Izycka, CERN 79-08, 1979.
21. K. Wündrich, unpublished, 1979.
22. K. T. Gillen, R. L. Clough, SAND 80-1796, 1980.
23. S. N. Lawandy, C. Hepburn, Elastomerics, **112**, 12, 42 (1980).
24. K. Rauhut, S. Rösinger, H. Wilski, Kunststoffe, **70**, 89 (1980).
25. E. Hegazy et al., J. Appl. Polym. Sci., **26**, 1361 (1981).
26. E. A. Salazar, D. A. Bouchard, D. T. Furgal, SAND 81-1906, 1981.
27. T. Seguchi et al., Radiat. Phys. Chem., **18**, 671 (1981).
28. H. Wilski et al., Colloid Polym. Sci., **259**, 818 (1981).
29. T. Seguchi et al., private communication, 1983.
30. H. Wilski, E. Gaube, S. Rösinger, Colloid Polym. Sci., **260**, 559 (1982).
31. J. Voigt, H. Wilski, Consultant's Meeting on Radiation Degradation of Organic Materials and Components used in Nuclear Reactor Environments, Cadarache, France, April 25–27, 1983.
32. D. J. Harmon, Textile Res. J., **27**, 318 (1957).
33. H. Wilski, J. Polym. Sci., Polym. Symp., **71**, 13 (1984).
34. A. A. Benderly, B. S. Bernstein, J. Appl. Polym. Sci., **13**, 505 (1969).
35. S. A. Segazy, T. Seguchi, S. Machi, J. Appl. Polym. Sci., **26**, 2937 (1981).
36. H. Busch, Kolloid-Z., **186**, 97 (1962).
37. W. Knappe, A. Zyball, Kunststoffe, **63**, 536 (1973).
38. E. Wolters, S. Rösinger, Kunststoffe, **63**, 605 (1973).
39. W. H. Buckalew, F. J. Wyant, SAND 85-0209, 1985.
40. W. Morell, H. Rost, International Conference on Nuclear Power Plant Aging Availability Factor and Reliability Analysis, San Diego, USA, July 8–12, 1985.
41. J. R. Brown, J. H. O'Donnell, J. Appl. Polym. Sci., **19**, 405 (1975).
42. J. R. Brown, J. H. O'Donnell, J. Appl. Polym. Sci., **23**, 2763 (1979).
43. K. Arakawa, T. Seguchi, N. Hayakawa, S. Machi, J. Polym. Sci., Polym. Chem. **21**, 1173 (1983).
44. Y. Kusama, T. Yagi, S. Okada, et al., Fourteenth Water Reactor Safety Information Meeting, Gaithersburg, USA, October 27–31, 1986.

49.

Polymer	Property	Air excluded	Ref.	≥ 10^5	Ref.	10^4	Ref.	10^3	Ref.
				Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h)					
								1. THERMOPLASTICS	
Poly(ethylene) high-density (HDPE)	σ_R	>50		>1	(13)			0.2^f	(13)
	ϵ_R	0.1–0.3		0.27	(13)			0.16^f	(13)
	σ_B								
	σ_{bB}								
low-density (LDPE)	σ_R	>60	(6)	>1	(19)	1^f	(6)	>1.5	(2)
	ϵ_R	0.4	(6)	0.35	(19)	0.3^f	(6)	0.4	(2)
				0.6	(3)	0.6	(3)	0.4	(3)
cross-linked (XLPE)	σ_R			1.5->5	(19)	>1.8	(22)	0.4	(2)
	ϵ_R	1.4	(18)	0.5–0.8	(19)	0.4–0.5	(16)	0.4	(2)
						0.4–0.5	(22)	2	(40)
Poly(propylene) (PP)	σ_R	0.7*	(6)	>0.5	(34)	0.09^f	(6)	0.06^f	(15)
						0.15	(25)		
	ϵ_R	0.03	(6)	0.15	(34)	0.015^f	(6)	0.03^f	(15)
		0.03	(25)			0.017	(25)		
	σ_B	0.25	(7)						
	σ_{bB}	>1.5	(7)			0.2	(7)		
	σ_{Bmax}	0.2	(7)						
	a_K								
Poly(vinyl alcohol) (PVAL)	σ_R	0.5*	(6)			0.25^{**f}	(6)		
	ϵ_R	0.4	(6)			0.35^f	(6)		
Poly(vinyl chloride) (PVC) unplasticized	σ_R	46	(6)			$> 8^f$	(6)	0.8^f	(5)
	ϵ_R	6	(6)			0.07^f	(6)	1^f	(5)
						0.04–0.1	(10)		
	σ_B								
	a_K								
plasticized	σ_R	>30	(6)	3->5	(19)	0.55^f	(6)	>1.5	(2)
						0.5	(35)	0.35^f	(36)
	ϵ_R	2	(6)	0.5–1	(19)	0.55^f	(6)	1.5	(2)
						0.6	(35)		
Poly(tetrafluoroethylene) (PTFE)	σ_R	0.01	(7)	0.006	(1)	>2	(40)		
	σ_{bB}					0.15	(7)		
	ϵ_R			0.0006	(1)				
	ϵ_{Bmax}	0.001	(7)						
	a_K			0.1	(1)				
Poly(tetrafluoroethylene-co-ethylene) (ETFE)	ϵ_R							0.3^f	(16)
Poly(methyl methacrylate) (PMMA)	σ_B	0.1–0.2	(14)	0.15	(1)				
	a_n								
	a_K			0.6	(1)				
Poly(methyl methacrylate-co-acrylonitrile) (AMMA)	σ_B	>10	(14)						
	a_n								

50.

	Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h)										
Property	500	Ref.	100	Ref.	50	Ref.	10	Ref.	5	Ref.	Remarks
σ_R					0.038^f	(13)			0.018^f	(13)	(13) f: 0.4 mm wires
									0.015–0.02	(13)	
ε_R					0.036^f	(13)			0.015^f	(13)	*Varying stabilizer
					0.006-0.035*	(31)			0.04–0.07	(13)	
									0.05	(12)	
σ_B									0.08	(12)	
									0.15	(12)	
σ_{yB}											
σ_R											(6) f: 0.1 mm films
ε_R					0.12	(8)					
σ_R	1.1*	(18)	>1.2	(22)			>0.6	(22)			*With antioxidant
	0.4	(27)									
ε_R	1*	(18)	0.4	(16)	0.7	(40)	0.25	(22)			
	0.3	(27)									
	0.7	(40)									
σ_R					0.021^f	(15)			0.01^f	(15)	(6) f: 0.1 mm films
											(15) f: 0.4 mm wires
ε_R					0.013^f	(15)			0.007^f	(15)	
					0.005-0.025**	(31)			0.04	(12)	* Up to 4 MGy slightly above 50%
σ_B									>0.1	(12)	**Varying stabilizer
a_K							0.03	(12)			
											(6) f: 0.1 mm films * 0.5–5 MGy slightly above 50% ** 0.25–0.9 MGy slightly above 50%
σ_R									0.15^f	(5)	(5) f: 0.4 mm wires
ε_R									>0.1^f	(5)	(6) f: 0.1 mm films
									0.015	(12)	
σ_B									0.03	(12)	Values for ε_R have
σ_B									0.02	(12)	wide range
a_K					0.15^f				0.13^f		(6) f: 0.1 mm films
σ_R											(36) f: 0.025 mm fibres
ε_R	0.3	(40)			>0.1^f				0.12^f		
			0.2	(40)			>0.05	(40)			
ε_R	0.3^f	(16)									E/TFE = 1/3
											(16) f: 0.4 mm
σ_B					0.15–0.25	(14)					
a_n					0.25	(14)					
σ_B					0.35	(14)					AN/MMA = 70/30
a_n					0.2	(14)					

References page VI-464

51.

Polymer	Property	Air excluded		Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h) $\geq 10^5$	Ref.	10^4	Ref.	10^3	Ref.
Poly(styrene) (PS)	σ_R	>40	(6)	>50	(1)	1.15[f]	(6)		
		>10	(14)						
	ε_R	7	(6)			0.5[f]	(6)		
		11	(28)						
	a_n	11	(28)						
	a_K			>50	(1)				
Poly(styrene)/ Poly(butadiene) (PS/PB)	σ_R	>3	(30)						
	ε_R	2	(30)						
	a_n	2.3	(30)						
Poly(styrene)/Poly(butadiene-co-acrylonitrile) (ABS)	σ_B	>1	(7)						
	σ_{Bmax}	0.4	(7)						
	a_K	0.5	(7)						
Poly(butadiene)	σ_{Bmax}	0.4	(7)						
	a_K	0.5	(7)						
Poly(styrene-co-acrylonitrile) (SAN)	σ_R	>50	(6)			0.85[f]	(6)		
	ε_R	1	(6)			0.6[f]	(6)		
	σ_B	>10	(14)						
	a_n								
Poly(oxymethylene) (POM)	σ_R	0.1	(37)	0.075	(37)				
		0.04*	(37)	0.04*	(37)				
	σ_B	0.07	(37)	0.06	(37)				
		0.04*	(37)	0.04*	(37)				
	ε_R	0.027	(37)	0.027	(37)			0.02	(38)
		0.015*	(37)	0.015*	(37)				
		a_K						0.015	(38)
Poly(ethylene terephthalate) (PETP)	σ_R	6.5	(6)	5[f]	(1)	4.4[f]	(6)	>1[f]	(4)
	ε_R	2.3	(6)	2	(1)	1.8[f]	(6)	1[f]	(4)
Poly(carbonate) (PC)	σ_S	3	(14)						
	σ_R	1.3							
		2.5	(14)						
	ε_R	0.5							
		0.9	(14)						
Poly(ε-caprolactam) (PA-6) and	σ_R	>50		>60	(1)	0.20[f]	(36)	0.09[f]	(32)
								0.15[f]	(36)
Poly(hexamethylene adipamide) (PA-6.6)	ε_R							0.15[f]	(32)
Polysulfon	σ_B	>3.5	(41)			1.7	(41)		
	σ_{bB}	>3.5	(41)	2.0	(42)	1.7	(41)		
		>6	(42)	40					
Cellulose acetate (CA)	σ_R	0.3	(6)	0.35	(1)	0.4[f]	(6)		
	ε_R	0.15	(6)	0.15	(1)	0.15[f]	(6)		
Cellulose acetobutyrate (CAB)	σ_R			0.3	(1)				
		ε_R			0.2	(1)			
Cellulose (Viscose rayon)	σ_R							0.15[f]	(32)
	ε_R							0.15[f]	(32)

Property	500	Ref.	100	Ref.	50	Ref.	10	Ref.	5	Ref.	Remarks
	Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h)										
σ_R					1	(14)	1	(28)			(6) f: 0.1 mm films
ε_R							0.5	(28)			Values for ε_R have wide range
a_n					0.55	(14)	0.5	(28)			
σ_R							0.9	(30)			Impact PS with 8% PB
ε_R							0.45	(30)			
a_n							0.3	(30)			
											High-impact PS
											S/AN = 75/25
σ_Y					0.55	(14)					(6) f: 0.1 mm films
a_n					0.35	(14)					
											Samples injection moulded *Samples pressed
σ_R									>0.1'	(4)	(4) f: 0.25 mm wires
ε_R									>0.1'	(4)	(6) f: 0.1 mm films
σ_Y					>1	(14)					
σ_R					>1	(14)					
ε_R					>1	(14)					
σ_R					0.05'	(33)			0.02'	(33)	(1) PA-6.6 (32) PA-6 + PA-6.6 Tire Cord
ε_R					0.045'	(33)			0.02'	(33)	(33) PA-6 f: 0.4 mm wires (36) PA-6 + PA 6.6 f: 0.025 mm fibres
											(6) f: 0.1 mm films
											Tire cord

References page VI-464

2. ELASTOMERS

Polymer	Property	Air excluded		Half-Value Dose (MGy) In Air at Different Dose Rates (Gy/h) ≥ 10^5	Ref.	10^4	Ref.	10^3	Ref.
Poly(isoprene) cis (NR)	σ_R			3	(1)	>1	(12)		
(Natural rubber)						1	(29)		
	ϵ_R			1–1.5	(1)	>1	(12)		
						1.5	(29)		
Poly(butadiene-co-styrene) (SBR)	σ_R			4	(1)				
(Styrene/butadiene rubber)	ϵ_R			0.5	(1)			0.6–1	(17)
Poly(butadiene-co-acrylonitrile) (NBR)	σ_R			>10	(1)	>2	(29)	>1.5	(2)
(Nitrile/butadiene rubber)								0.3	(3)
	ϵ_R			0.5	(1)	0.45	(29)	0.3–0.7	(2)
				0.3	(3)	0.3	(3)	0.9	(21)
Poly(chloroprene) (CR)	σ_R			2	(1)	>2	(22)	>1.5	(22)
(Chloroprene rubber)				>5	(19)	>2	(44)	>1.5	(2)
	ϵ_R			0.5	(1)	0.5	(16)	0.5	(22)
				0.3	(19)	0.35	(44)	0.5–0.8	(2)
								0.25	(44)
Poly(isobutene-co-isoprene) (IIR)	σ_R			0.4	(1)				
(Butyl rubber)	ϵ_R			>0.5	(1)				
Poly(isobutene-co-isoprene), brominated (BIIR)	σ_R							>1.5	(2)
(Bromo butyl rubber)	ϵ_R							0.2	(2)
Poly(ethylene) (CSM) chlorosulfonated	σ_R			>5	(19)	>2.5	(22)	>1.5	(2)
						>2	(44)	>2	(44)
						0.8–1	(16)		
						>3	(29)		
	ϵ_R			0.3–0.4	(3)	0.3–0.4	(3)	0.3–0.4	(3)
				0.4–0.6	(19)	0.6–1	(16)	0.9	(2)
						0.4	(29)	1	(44)
Poly(ethylene-co-propylene) (EPM, EPDM)	σ_R	0.6	(43)	0.5–>5*	(19)	>1.8	(22)	1.2	(22)
(Ethylene/propylene rubber)	ϵ_R	0.45	(43)	0.3–0.6	(19)	0.6	(16)	0.5	(16)
						0.6	(40)		
						0.4	(43)	0.4	(21)
Poly(ethylene-co-vinyl acetate) (EVM)	σ_R			>5	(19)				
(Ethylene/vinyl acetate rubber)	ϵ_R			0.5	(19)	1.7	(40)		
Poly(ethyl acrylate) (ACM)	σ_R			1.5	(1)	1.1	(29)	>1.5	(2)
(Ethyl acrylate rubber)				>5	(19)				
	ϵ_R			0.35	(1)	0.7	(29)	0.25–1	(2)
				0.3	(19)				
Poly(vinylidene fluoride-co-hexafluoro-) propylene) (FKM)	σ_R			>5	(19)				
(Fluorocarbon rubber)	ϵ_R			0.25	(19)			0.15–0.25	(21)
Poly(chlorotrifluoro-ethylene) (CFM)	σ_R			1	(1)				
Polyurethane rubber (AUEU)	σ_R			0.3	(19)	1.2	(29)		
	ϵ_R			0.25	(19)	1.2	(29)		

Property	500	Ref.	100	Ref.	50	Ref.	10	Ref.	5	Ref.	Remarks
	Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h)										
σ_R									0.1	(12)	
ε_R									0.07	(12)	
σ_R	>1	(22)	1	(22)			0.5	(22)			
	>2	(44)									
ε_R	0.45	(22)	0.35	(22)			0.25	(22)			
σ_R	>2.5	(22)	>2.5	(22)			>0.5	(22)			
ε_R	1	(16)	1	(22)			0.6	(22)	0.1–0.4	(12)	
	0.75	(44)									
σ_R	>1.5	(22)	0.9	(22)	>1	(43)	0.6	(22)			*Some compounds show
ε_R	0.45	(16)	0.4	(16)	0.3	(40)	0.3	(22)	0.05–0.2	(12)	a minimum slightly below 50%
	0.3	(40)			0.2	(43)					between 0.5 and 5 MGy
	0.25	(44)									
ε_R	0.8	(40)			0.5	(40)					

References page VI-464

55.

Polymer	Property	Air excluded	Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h): ≥ 10^5	Ref.	10^4	Ref.	10^3	Ref.
Polysulfide rubber (TM)	σ_B		0.5	(1)				
	ε_B		0.1	(1)				
Silicone rubber (Q)	σ_B		1.5	(1)	2	(44)	>0.5	(2)
			0.7–1	(19)			2	(44)
	ε_B		0.15–0.25	(1)	0.5	(39)	0.2	(16)
			0.15	(19)	0.6	(40)	0.2–0.6	(2)
					0.2	(44)	0.15	(44)

3. THERMOSETS

Polymer	Property	Air excluded	≥ 10^5	Ref.	10^4	Ref.	10^3	Ref.
Phenol–formaldehyde resin (PF)	σ_{bB}		4	(1)				
with asbestos	σ_{bB}		30	(9)				
	a_n		>20	(9)				
with graphit	σ_{bB}		>50	(1)				
	a_K		>50	(1)				
with mineral flour	σ_{bB}		30	(9)				
	a_n		>20	(9)				
with cotton	σ_{bB}		3.4	(9)				
	a_n		0.3	(9)				
with wood flour	σ_B		5	(9)				
	a_n		3	(9)				
with paper laminated	σ_{bB}		1.5	(1)				
	a_K		0.5	(1)				
with linen cloth	σ_{bB}		1	(1)				
	a_K		0.1	(1)				
Urea–formaldehyde resin (UF) with cellulose	σ_{bB}		0.5	(1)				
	a_K		>10	(1)				
Melamine–formaldehyde resin (MF) with asbestos	σ_{bB}		>30	(11)				
	a_n		>10	(11)				
with cellulose	σ_{bB}		1	(1)				
	a_K		>10	(1)				
Phenolic anilin resin	σ_{bB}		40	(1)				
Furan resin	σ_{bB}		>50	(1)				
with asbestos and carbon black	σ_{bB}		>50	(1)				
Polyester resin (UP) with glass fibre	σ_{bB}		10–50	(20)				
with mineral flour and glass fibre	σ_{bB}		>30	(11)				
	a_n		>10	(11)				
with mineral flour	σ_{bB}							
Polyurethane resin (PUR) with mineral flour	σ_{bB}		30	(20)				

Property	Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h) 500	Ref.	100	Ref.	50	Ref.	10	Ref.	5	Ref.	Remarks
ε_R	0.2	(16)									
	0.2	(40)			0.2	(40)			0.05	(40)	
							>1	(9)			55% filler
											47% filler
											50% filler
							0.2	(9)			(fabric shreds)
							2.3	(9)			47% filler
							1	(9)			
							>1	(11)			46% filler
							>0.5	(11)			(long fibres)
							>1	(11)			50% mineral flour
							>0.5	(11)			15% glass fibre
σ_{bB}	>7	(24)									82% quartz sand

References page VI-464

Polymer	Property	Air excluded	Half-Value Dose (MGy) in Air at Different Dose Rates (Gy/h)				
			$\geq 10^4$	Ref.	500	Ref.	Remarks
Epoxy resin (EP)	σ_{bB}		2–20	(20)			
with glass fibre	σ_{bB}		25–>100	(20)			
with graphit	σ_{bB}		50	(20)			
with mineral flour	σ_{bB}		10–30	(20)	7	(24)	85% quartz sand
with cotton	σ_{bB}		1	(20)			
Polyphenylene sulfide resin (PPS)	σ_{bB}		>50	(20)			
Polyimide resin (PI)	σ_{bB}		50–100	(20)			
Silicone resin (SI) with glass fibre	σ_{bB}		>50	(20)			

[a] Reference number given in parentheses.

58.

1 of 25 Complete Record
213260000 Summary
Chapter CH= 21326
Type TY= 213260
Unit UN= 213260000

Chapter Title: **Radiation-resistant Polymers**

Author: Clough, Roger
Institution: Sandia National Labs
Source: Encyclopedia of Polymer Science and Engineering, Second Edition, Vol. 13, Pages 667-708.
Number of Sections = 4 Tables = 3 Descriptors = 145 References = 167

Abstract:
The interaction mechanism of ionizing radiation with polymeric materials is outlined, including a discussion of the important role played by free radicals in radiation-induced degradation in inert and oxygen atmosphere. Cross-linking, scission, and gas formation are discussed that lead to changes in useful properties. The relationship between polymer structure and radiation resistance is mentioned. Techniques for studying radiation-induced degradation are presented, including the improvement of radiation tolerance. Stabilizers and time-dependent dose-rate effects and postirradiation effects are described. Accelerated radiation-aging experiments predict long-term radiation-oxidation resistance. Vol. 13, pp. 667-708, 165 Refs. to March 1987.

Section Headings:

Tables:

Table 2. Dose Required to Reduce Tensile Elongation to Half the Initial Value, for Polyethylene Containing Stabilizers**a <SELECT TN=21326T2>
Table 3. Dose Required**a to Reduce the Elongation at Break**b to 50% of Original, Under Low Dose-rate Conditions in Air**c Versus High Dose-rate (or Inert Atmosphere) Conditions**d <SELECT TN=21326T3>

Figure Titles:

Fig. 1. Effect of gamma-irradiation on the elastic modulus of A, Buna-N; B, polybutadiene; C, a GR-S-type rubber; and D, natural rubber (31). To convert Gy to rad, multiply by 100.

Fig. 2. Effect of radiation dose on a polychloroprene: elongation at break (E), hardness by Shore D (H), and tensile strength in N/mm**2 (R). Radiation was with combined gamma (10**5 Gy/h or 10**7 rad/h), thermal neutrons, n (3.5 TIMES 10**11 n/cm**2.s) and fast neutrons (E > 1MeV, 2.5 TIMES 10**10 n/cm**2.s) (32). To convert Gy to rad, multiply by 100. To convert N/mm**2 to psi, multiply by 145. Courtesy of CERN Scientific Information Service.

Fig. 3. Stress-strain curves for poly(methyl methacrylate) irradiated in the Oak Ridge graphite reactor at about 25 DEGREES C in an inert atmosphere (33): A, 4 TIMES 10**5 Gy; B, 2 TIMES 10**5 Gy; C, 4 TIMES 10**4 Gy; D, unirradiated; SOLID CIRCLE = breaking point. To convert Gy to rad, multiply by 100. To convert MPa to psi, multiply by 145.

Fig. 4. Effect of radiation on an epoxy novolac material: flexural strength S in N/mm**2, deflection at break D in mm, elastic modulus M in N/mm**2. Irradiation conditions were combined gamma (1.5 TIMES 10**6 Gy/h), thermal neutrons 4.5 TIMES 10**12 n/cm**2.s, and fast neutrons (2.5 TIMES 10**12 n/cm**2.s) (34). To convert Gy to rad, multiply by 100. To convert N/mm**2 to psi, multiply by 145. Courtesy of CERN Scientific Information Service.

Fig. 5. Foamed poly(methyl methacrylate) (b) obtained by irradiating (a) and heating it immediately afterward above the softening point (42).

Fig. 6. Concentration dependence of the radiation protection factor (Pf) for several aromatic additives in PMMA. Pf = G(So)/G(Sa) where G(So) = scission yield of PMMA without additives, and G(Sa) = scission yield in the presence of additives. +, benzene; SOLID CIRCLE, naphthalene; CIRCLE, phenanthrene; SOLID TRIANGLE, anthracene; TRIANGLE, pyrene, TIMES, benz(alpha)anthracene (50).

Fig. 7. Cross-link yields in irradiated butadiene-styrene copolymers and in physical mixtures of polybutadiene and polystyrene (gamma-irradiation in vacuo). SOLID CIRCLE, Copolymer (emulsion polymerization); CIRCLE, physical mixture (51).

Fig. 8. Radiation effects for elastomers under nonoxidizing conditions (61); BOX, incipient to mild damage, nearly always usable; SOLID BOX, mild to moderate damage, utility often satisfactory; BOX, moderate to severe damage, not recommended for use. To convert Gy to rad, multiply by 100.

Fig. 9. Radiation effects for thermosetting resins under nonoxidizing conditions (61): BOX, incipient to mild damage, nearly always usable; SOLID BOX, mild to moderate damage, utility often satisfactory; BOX, moderate to severe damage, not recommended for use. To convert Gy to rad, multiply by 100.

Fig. 10. Radiation effects for thermoplastic resins under nonoxidizing conditions (61): BOX, incipient to mild damage, nearly always usable; SOLID BOX, mild to moderate damage, utility often satisfactory; BOX, moderate to severe damage, not recommended for use. To convert Gy to rad, multiply by 100.

Fig. 11. Relative tensile strength of polystyrene samples as a function of radiation dose (1 Gy = 100 rad). SOLID CIRCLE, irradiation under nitrogen (4.7 TIMES 10**3 Gy/h), CIRCLE, irradiation in air (13 Gy/h) (63).

Fig. 12. Hardness profiles for gamma-irradiated Viton fluorelastomer samples, 1.9-mm thick (1 Gy = 100 rad). TIMES, unirradiated material; CIRCLE, 1.8 TIMES 10**3 Gy/h in air to 1.9 TIMES 10**6 Gy; SOLID BOX, 9 TIMES 10**3 Gy/h in vacuum to a dose of 1.9 TIMES 10**6 Gy (73).

Fig. 13. Polished cross-sections of cross-linked polyethylene cable insulation material, illustrating heterogeneous oxidation at high dose rate in air (1 Gy = 100 rad). (a) Unirradiated material; (b) 8.9 TIMES 10**3 Gy/h to 1.2 TIMES 10**6 Gy in air; (c) 1.1 TIMES 10**4 Gy/h to 1.1 TIMES 10**6 Gy under vacuum. Samples were stripped off the copper conductor, and irradiated as hollow tubes; wall thickness = 0.75 mm (90).

Fig. 14. (a) Ultimate tensile elongation of PVC cable jacketing gamma-irradiated at 60 DEGREES C at various dose rates (94); 1 Gy = 100 rad. CIRCLE, 9.4 TIMES 10**3 Gy/h; SOLID CIRCLE, 3.6 TIMES 10**3 Gy/h; TRIANGLE, 7.1 TIMES 10**2 Gy/h; SOLID TRIANGLE, 1.7 TIMES 10**2 Gy/h; BOX, 3.5 TIMES 10**1 Gy/h. (b) Tensile strength (relative) of nylon wires with a diameter of 0.4 mm as a function of gamma-irradiation in air with different dose rates (1 Gy = 100 rad) (95). BOX, TRIANGLE, CIRCLE, type A; SOLID BOX, SOLID TRIANGLE, SOLID CIRCLE, type B; BOX, SOLID BOX, 2000 Gy/h; TRIANGLE, SOLID TRIANGLE, 43.5 Gy/h; CIRCLE, SOLID CIRCLE, 4.45 Gy/h.

Fig. 15. G values for oxygen consumption as a function of the antioxidant concentration for an ethylene-propylene copolymer containing three different additives (105). CIRCLE, N,N'-diphenyl-p-phenylenediamine; HALF CIRCLE, nickel dibutyl dithiocarbamate; SOLID CIRCLE, tetrakis[methylene-3(3,5-di-t-butyl-4-hydroxyphenyl)propionate] methane (Irganox 1010).

Fig. 16. Oxygen absorption rates in samples of poly(ethylene oxide) (PEO) containing different amounts of the stabilizer 2,6-di-t-butyl-p-cresol (in mmol/kg PEO as noted on the curves). Samples were irradiated continuously at 440 Gy/h (1 Gy = 100 rad) (106).

Fig. 17. Postirradiation oxidation of polypropylene film after gamma-irradiation to 2 TIMES 10**4 Gy at 1.4 TIMES 10**4 Gy/h (99) (1 Gy = 100 rad): SOLID CIRCLE, no additive; TRIANGLE, beta-(3,5-di-t-butyl-4-hydroxyphenyl)propionate; CIRCLE, 1,2,2,6,6-pentamethyl-4-stearoylpiperidine; +, 2,2,6,6-tetramethyl-4-nitrosopiperidine. Courtesy of the American Chemical Society.

Fig. 18. Changes in relative tensile strength of a polypropylene material as a function of irradiation (91). A, 0.3-mm sample thickness, irradiated at 5 TIMES 10**6 Gy/h under vacuum; B, 0.3-mm sample thickness, irradiated at 5 TIMES 10**6 Gy/h under vacuum, followed by heating 1 h at 80 DEGREES C; C, 0.3-mm sample thickness, irradiated in air at 10**4 Gy/h; D, 1.0-mm sample thickness, irradiated in air at 10**6 Gy/h and left standing two months before testing; E, 1.0-mm sample thickness, irradiated in air at 4 Gy/h; F, 0.4-mm diameter wire, irradiated in air at 4 Gy/h; (1 Gy = 100 rad). To convert N/mm**2 to psi, multiply by 145.

Descriptors:

Rays and x rays readily penetrate polymeric materials, whereas alpha-particle radiation can be strongly attenuated, giving rise to degradation effects only near the surface. In the case of radiation chemistry of solid polymers, the mobility of the radicals is much less than that of radicals in the liquid or gas phase, with the result that radical lifetimes can be very long (ie, minutes, days, weeks, or longer at room temperature).

4 of 25 Complete Record
213261002 Text
Chapter CH= 21326
Type TY= 213261
Unit UN= 213261001

Chapter Title: Radiation-resistant Polymers
Text continued from 213261001
Text continues in 213261003
Section Heading: The Interaction of Radiation with Polymers (continued)

Text:
It is useful to draw comparisons between radiation chemistry and photochemistry (qv). In photochemistry, particular chromophores located at specific sites in the molecule absorb photons of a specific energy leading to the production of a specific excited molecular state or states. These excited-state sites can be expected to undergo a certain set of defined reactions. By comparison, radiation chemistry is highly nonspecific. Electron ejections and excitations occur more or less at random throughout the molecular structure, and a wide range of different excited states are produced, including many highly excited states with a high probability of direct dissociation. The primary reaction products form a complicated mixture that is strongly influenced by the relative proportion of different molecular structures present throughout the material. For example, the production of methane is strongly affected by the total number of methyl groups present in the system. However, because of energy-transfer processes, radiation-induced chemistry is not completely random. Energy can migrate over short distances, selectively causing relatively weak chemical bonds to break, or becoming trapped by certain functional groups, such as aromatic rings, that undergo efficient nonreactive decay to the ground state.

A number of different units used to describe the absorption of high energy radiation by materials are found in the literature. The most common is the rad, whereas the new SI unit is the Gray (Gy). The main units are interrelated by the following equation 1 Gy = 100 rad = 1 J/kg = 6.24 TIMES 10**15 eV/g = 10**4 erg/g The unit used widely to express radiation chemical yields for production of radicals, various gaseous products, cross-links, etc, is the G value. It is defined as the number of molecular changes of a given type resulting per 100 eV of absorbed energy.

Free-radical Reactions in Irradiated Polymers.

Homolytic bond cleavage from excited states in irradiated polymers can lead to a pair of free radicals via bond scission, involving the main-chain or side-chain substituents. In the case of radical formation by scission of bonds in the main polymer chain (illustrated in eq. 1 for a polyethylene molecule), a high proportion of radical reactions can be expected to involve the geminate pair, either by recombination (eq. 2) or by disproportionation (eq. 3). This occurs because in the solid polymer, the two chain-end macroradicals are trapped in close proximity by the surrounding matrix. Recombination (eq. 2) does not result in a net change in molecular structure; disproportionation (eq. 3) results in permanent cleavage of the polymer chain. -(-CH2-CH2-)- RIGHT sufficiently high dose rate or sufficiently thick samples, irradiation beyond the point at which the initially dissolved oxygen is used up can result in oxygen depletion in the interior. For samples undergoing irradiation in air at constant dose rate, and assuming that oxygen diffusion rates and oxidation yields remain relatively constant, a steady-state situation develops in which strong oxidation occurs near the edges, fueled by oxygen supplied from the surrounding atmosphere that continuously diffuses into the material. In the interior regions, degradation may proceed in the absence of oxygen or at reduced oxygen concentrations. The depth of significant oxidation for a given polymer depends on the oxygen-permeation rate and the characteristic oxygen-consumption rate [G(-O2)] per absorbed dose. The oxidation depth also depends on the rate at which radicals are generated, which is proportional to the dose rate. In comparing two samples of the same material that have been irradiated at two different dose rates, it could be expected that the depth of significant oxidation would be greater at the lower dose rate. At a sufficiently low dose rate, oxygen diffusion effects would disappear, resulting in homogeneous oxidation throughout. Because temperature affects the oxygen diffusion rate and also possibly other steps in the oxidation mechanism, the oxygen penetration depth depends on temperature as well as dose rate. Thus, polymeric samples irradiated in the presence of oxygen can undergo different changes in the interior and exterior regions. The relative size of these regions depends on sample thickness, oxygen pressure in the surrounding atmosphere, dose rate, and temperature (73).

At sufficiently high dose rates, oxidation takes place only at the immediate surface. In such cases, most of the material undergoes degradation under effectively anaerobic conditions. The overall property changes are often similar to those for samples irradiated under inert atmospheres, and the conclusions and figures presented previously may approximately apply. However, this is not always the case. For instance, for hard glassy materials, an oxidatively degraded surface layer may be much more susceptible to crack formation under stress. Such cracks, once formed, may propagate readily through the bulk of the sample, and properties such as flexural strength may reflect a significant surface effect (74). For situations that approach homogeneous oxidation, homogeneous-oxidationlike degradation behaviors are often approximated. When both oxidized and unoxidized (or slightly oxidized) regions comprise a significant fraction of the material, the material properties may be a complex sum of the individual properties of the two regions. Frequently, macroscopic properties of heterogeneously degraded samples are between those obtained with materials oxidized homogeneously and materials degraded under inert atmosphere. For a series of different samples with progressively deeper oxidation, properties often range progressively from near those of samples degraded in an inert atmosphere to near those of homogeneously oxidized samples (73).

Heterogeneous oxidation appears frequently. Many applications involve material thicknesses and dose rates that result in heterogeneous oxidation. In addition, for applications that may involve dose rates so low as to give homogeneous oxidation, accelerated radiation-aging experiments, performed to predict degradation behaviors, which employ short time periods and elevated dose rates frequently give rise to heterogeneous oxidation. As a rule of thumb on oxygen-diffusion effects, it can be noted (73) that many elastomers and flexible plastics exhibit strongly heterogeneous oxidation when samples ca 1-mm thick are irradiated in air over the dose-rate range of 10**2 -10**4 Gy/h (10**4 -10**6 rad/h). For hard, glassy materials with lower permeation rates, oxygen diffusion effects would be expected at a lower dose-rate range.

urea-formaldehyde resins
melamine-formaldehyde resins

21 of 25 Complete Record
213262002 Table
Chapter CH= 21326
Type TY= 213262
Unit UN= 213262002

Chapter Title: Radiation-resistant Polymers

Table: Table 2. Dose Required to Reduce Tensile Elongation to Half the Initial Value, for Polyethylene Containing Stabilizers**a

Table Data:

Stabilizer, 0.25%	Dose, 10**3 Gy**b
none	6
2-mercaptobenzimidazole	6
trilauryl phosphite	6
ionox 330**c	8
2-mercaptobenzothiazole	13
N,N'-di-(beta-naphthyl-p-phenylenediamine) (DPPD)	15
Santonox R**c	23
Santowhite powder, refined**c	24
phenothiazine, Ionol**c	
50:50	32
30:70	36

Table Footnotes:
**a Ref. 103; for samples containing two stabilizers, the combined concentration equaled 0.25%.
**b 1 Gy = 100 rad.
**c A hindered phenol derivative.

22 of 25 Complete Record
213262003 Table
Chapter CH= 21326
Type TY= 213262
Unit UN= 213262003

Chapter Title: Radiation-resistant Polymers

Table: Table 3. Dose Required**a to Reduce the Elongation at Break**b to 50% of Original, Under Low Dose-rate Conditions in Air**c Versus High Dose-